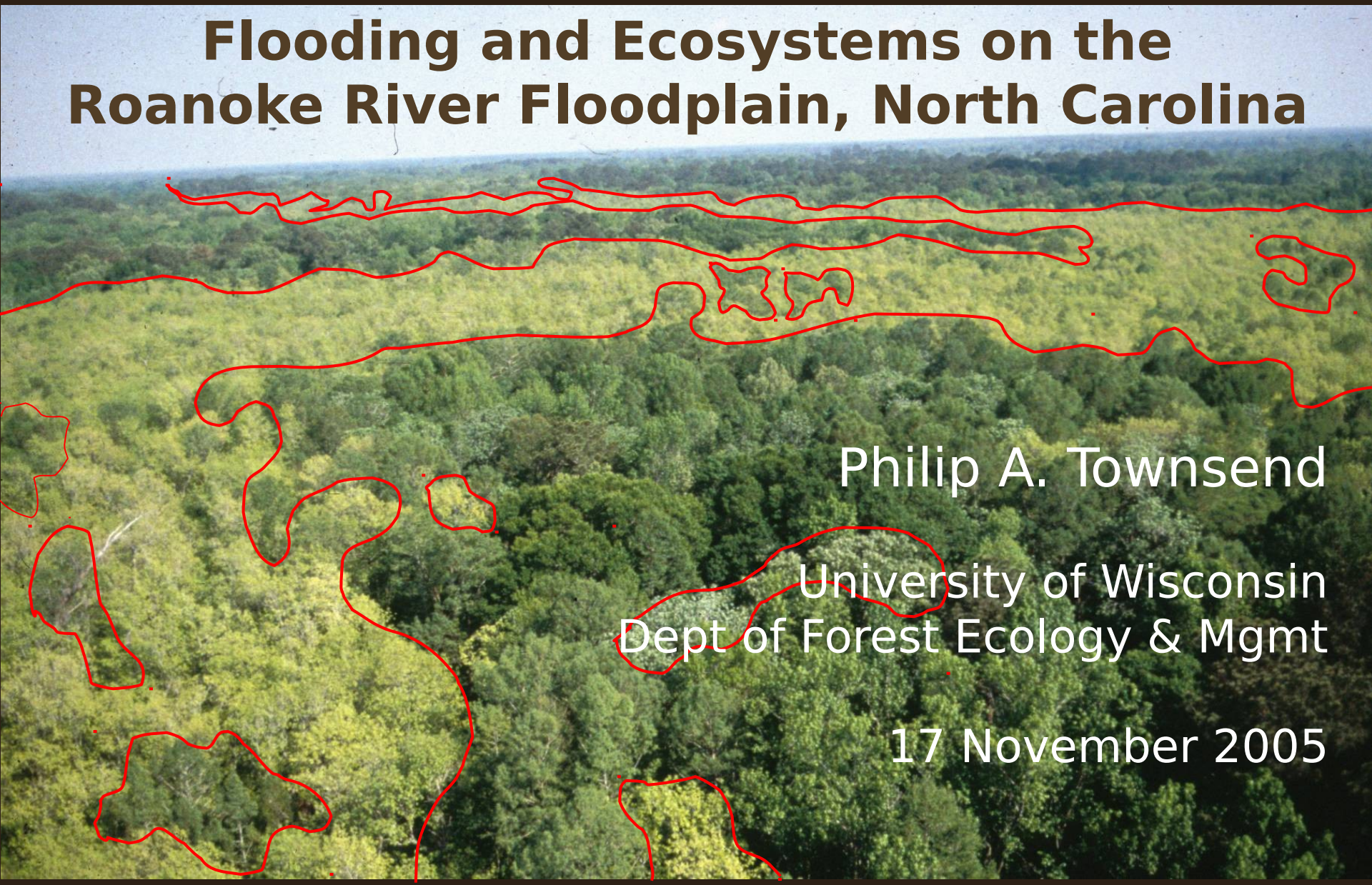
Flooding and Ecosystems on the Roanoke River Floodplain, North Carolina



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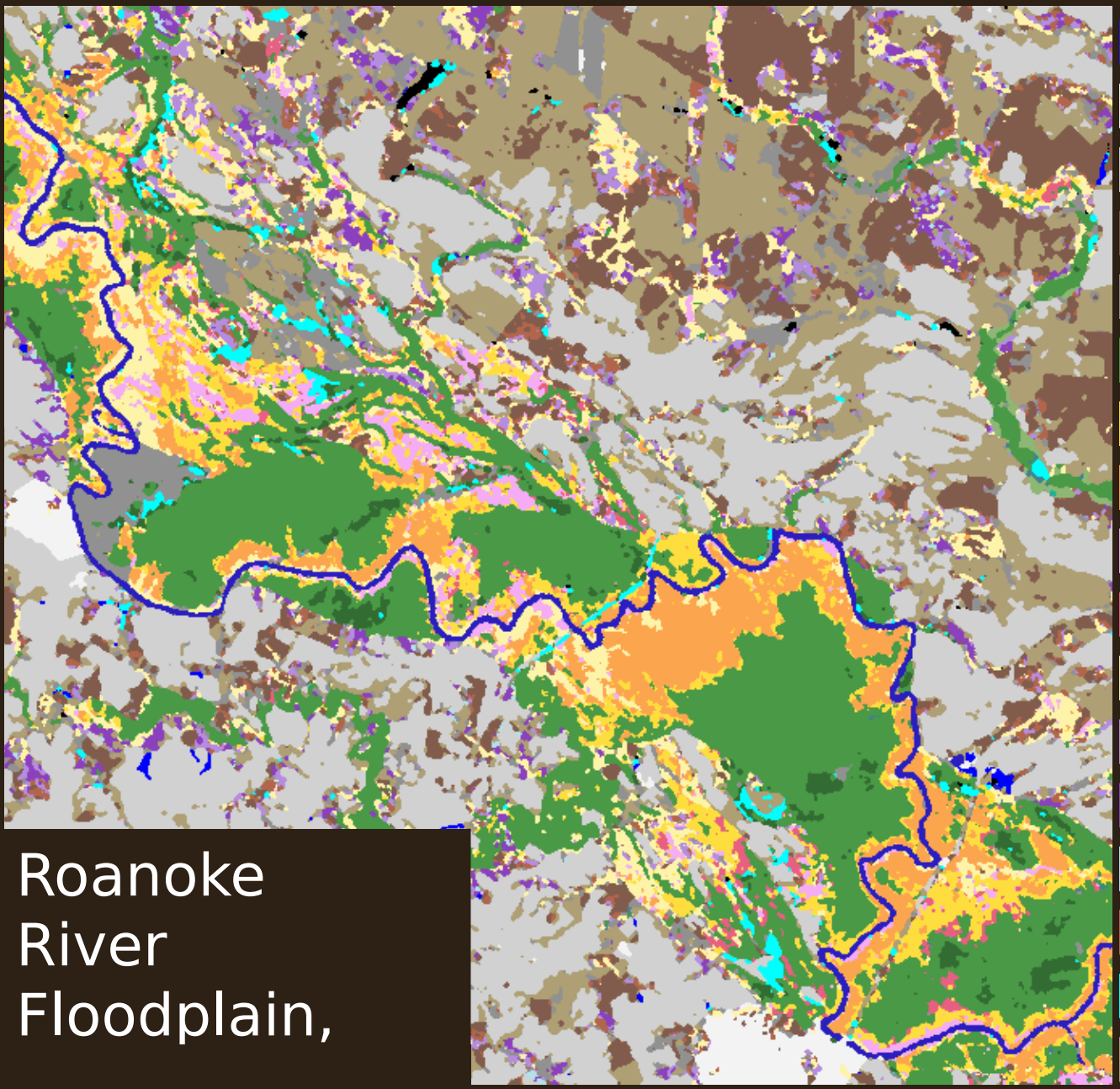
Vegetation of the Roanoke River Floodplain

- Diversity of forest community types
- Community type and distribution is controlled by hydrology
- Primarily duration and timing of flooding

Ecosystems of the Lower Roanoke



Roanoke River Floodplain,

- Brown Water
- Urban/Developed
- Agriculture/Bare
- Loblolly Pine
- Young Woodland/Forest
- Water Tupelo-Bald Cypress
- Red Maple-Oak-Water Tupelo
- Green Ash-Red Maple-Boxelder
- Sweetgum
- Mixed Oak-Red Maple-Sweetgum
- Sugarberry-American Elm-Green Ash
- (Cherrybark, WIllow) Oak-Sweetgum
- Beech
- White Oak-Mockernut Hickory
- Loblolly Pine-Mixed Oak
- Marsh and Sparsely Vegetated Wetland
- Successional/Shrub/Clearcut

Evolution of a DEM

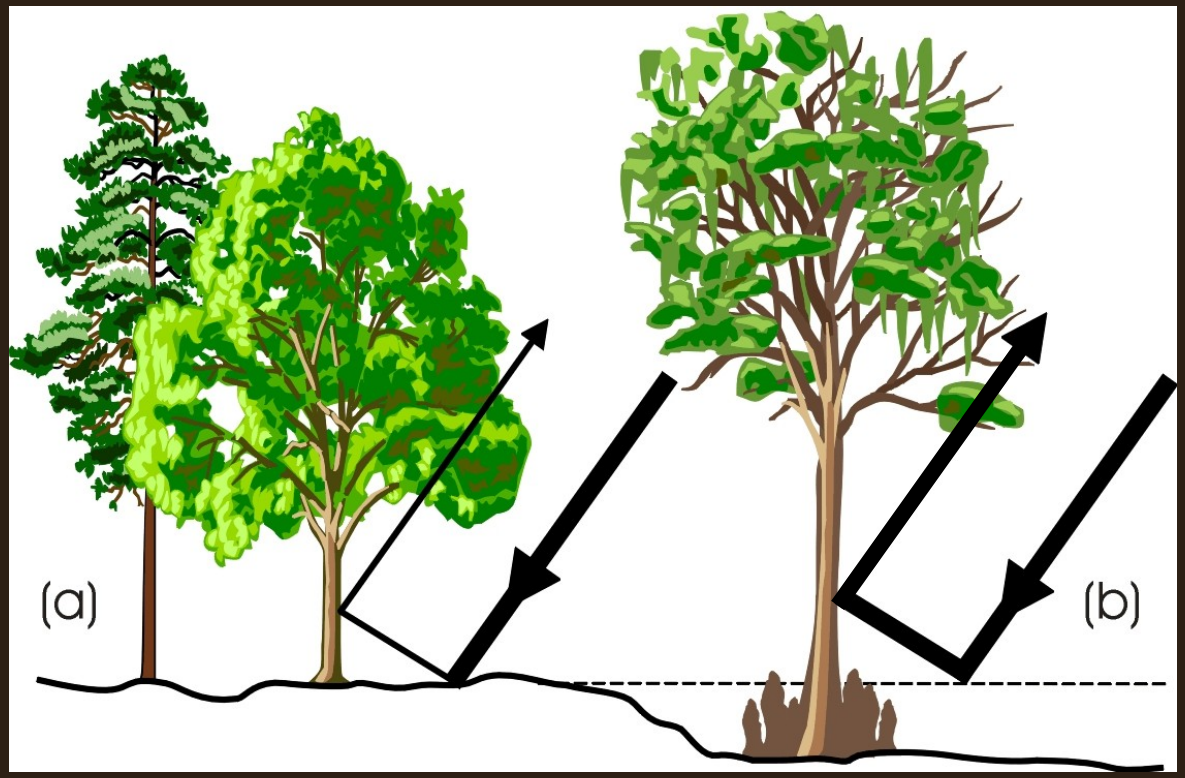
Roanoke River Floodplain

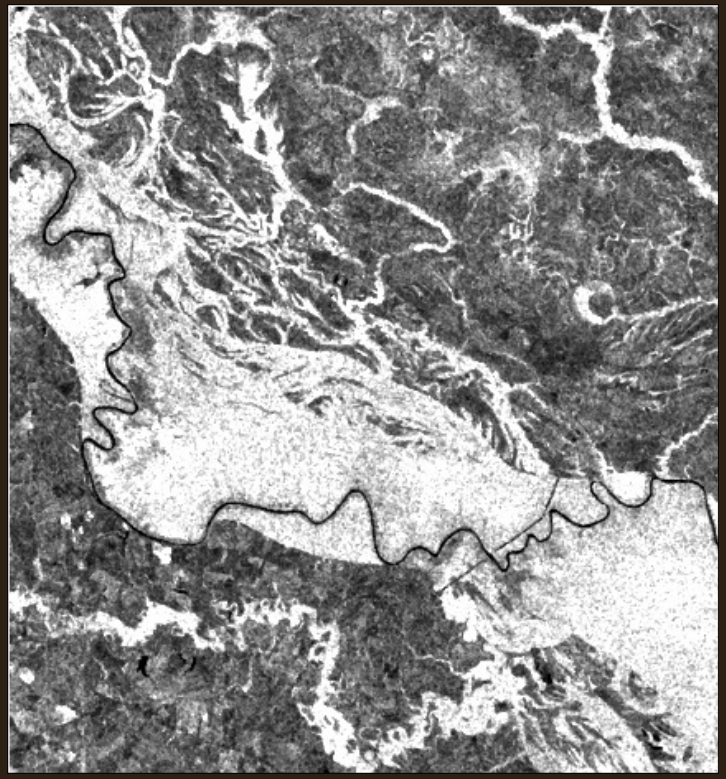
Topography on the Floodplain

- Very small differences in elevation can translate to large differences in hydrology
- Vegetation communities also respond to very small differences in flood regimes
- Therefore, some sort of topographic representation is needed to capture topographic differences on the order of inches, not feet

How to characterize changes in spatial extent and duration of flooding?

- Topography varies from centimeters to 5 m
- Answer: Imaging radar (SAR)



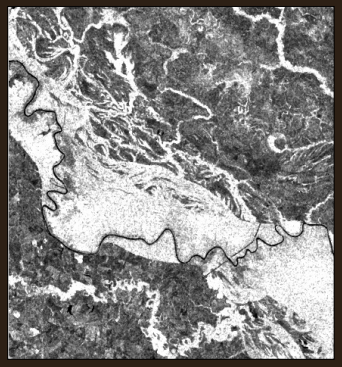
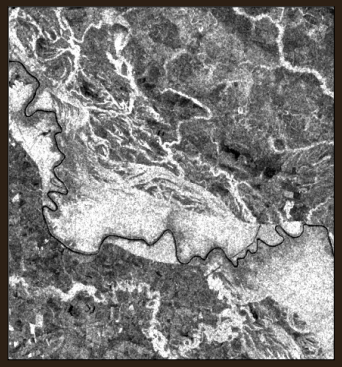
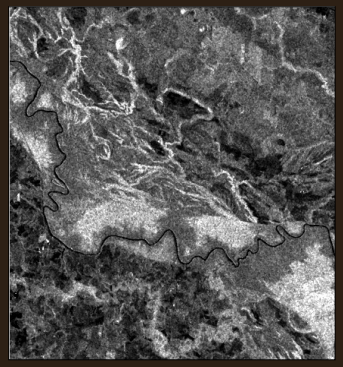
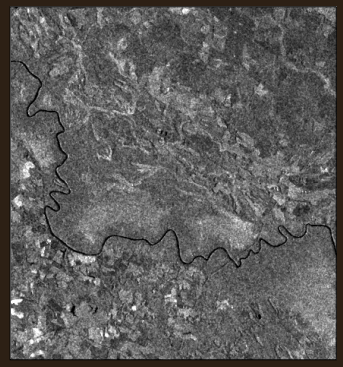


Why Radar?

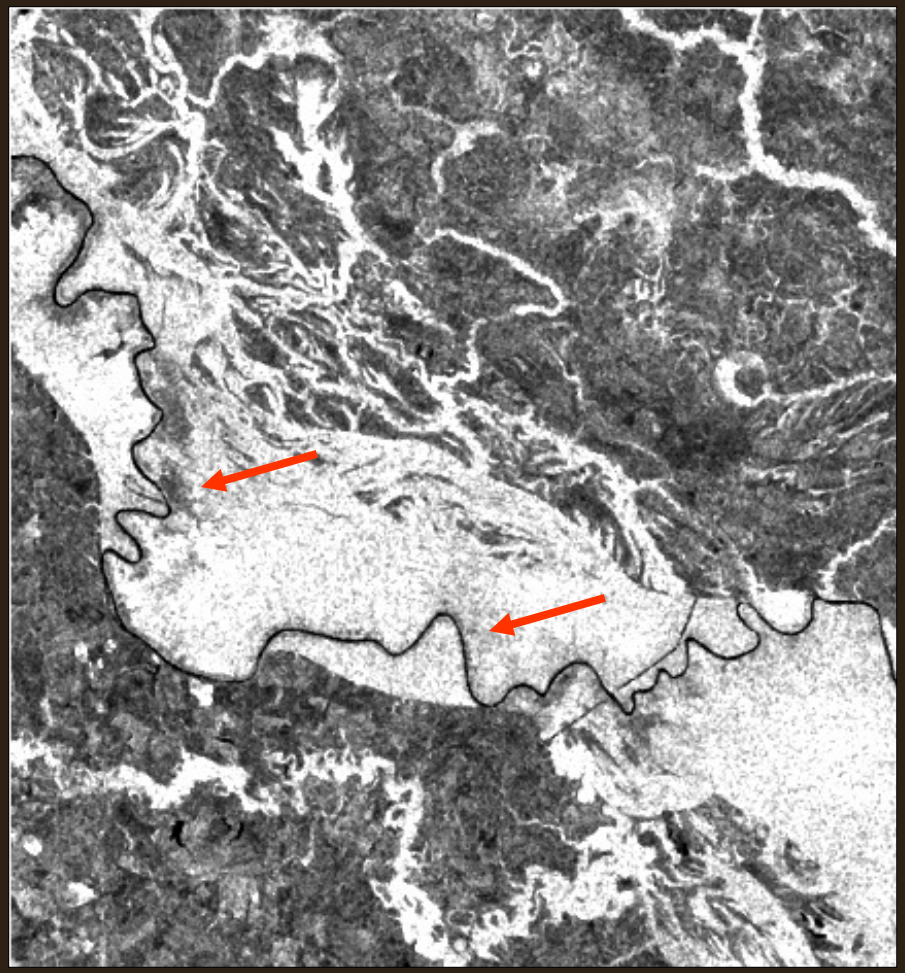
- Radar transmits through the atmosphere regardless of time of day or weather conditions (clouds).
- Radar can penetrate vegetation canopies at certain frequencies and polarizations.
- Flooded forests have bright radar responses (high “backscatter”).

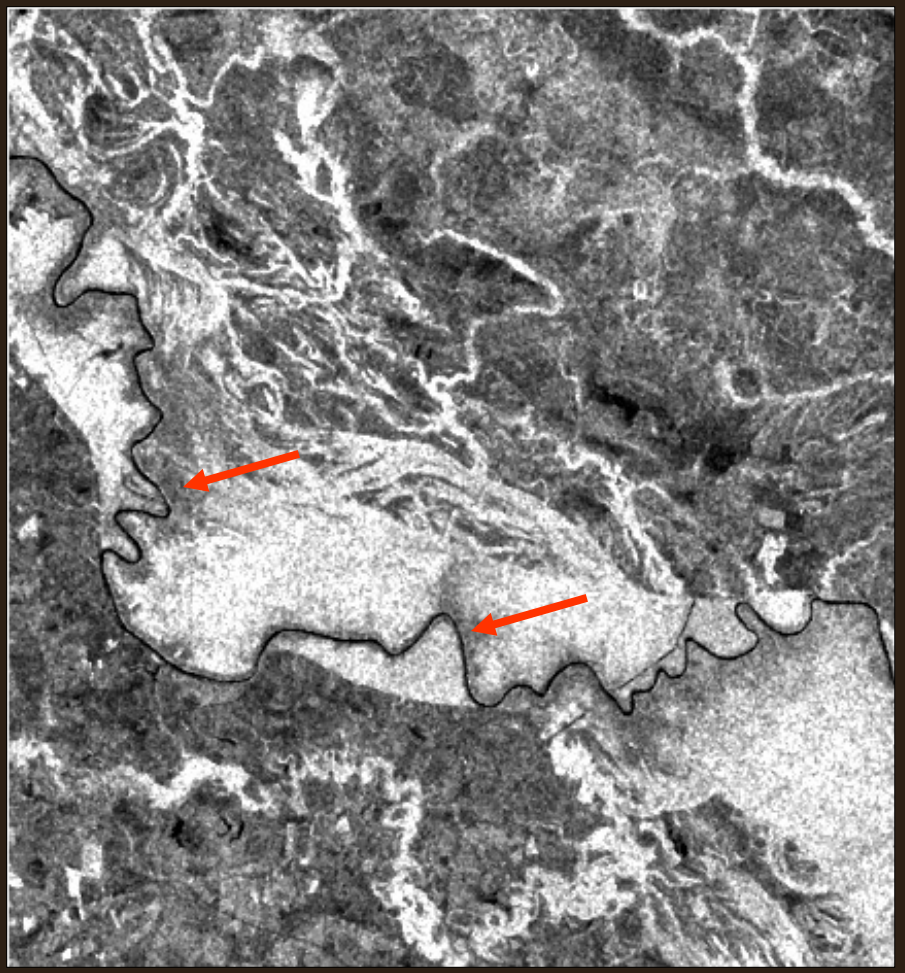
Approach (1)

- Something completely different:
- Use orbital (satellite) synthetic aperture radar imagery (SAR) to map flooding on specific dates at known discharge rates

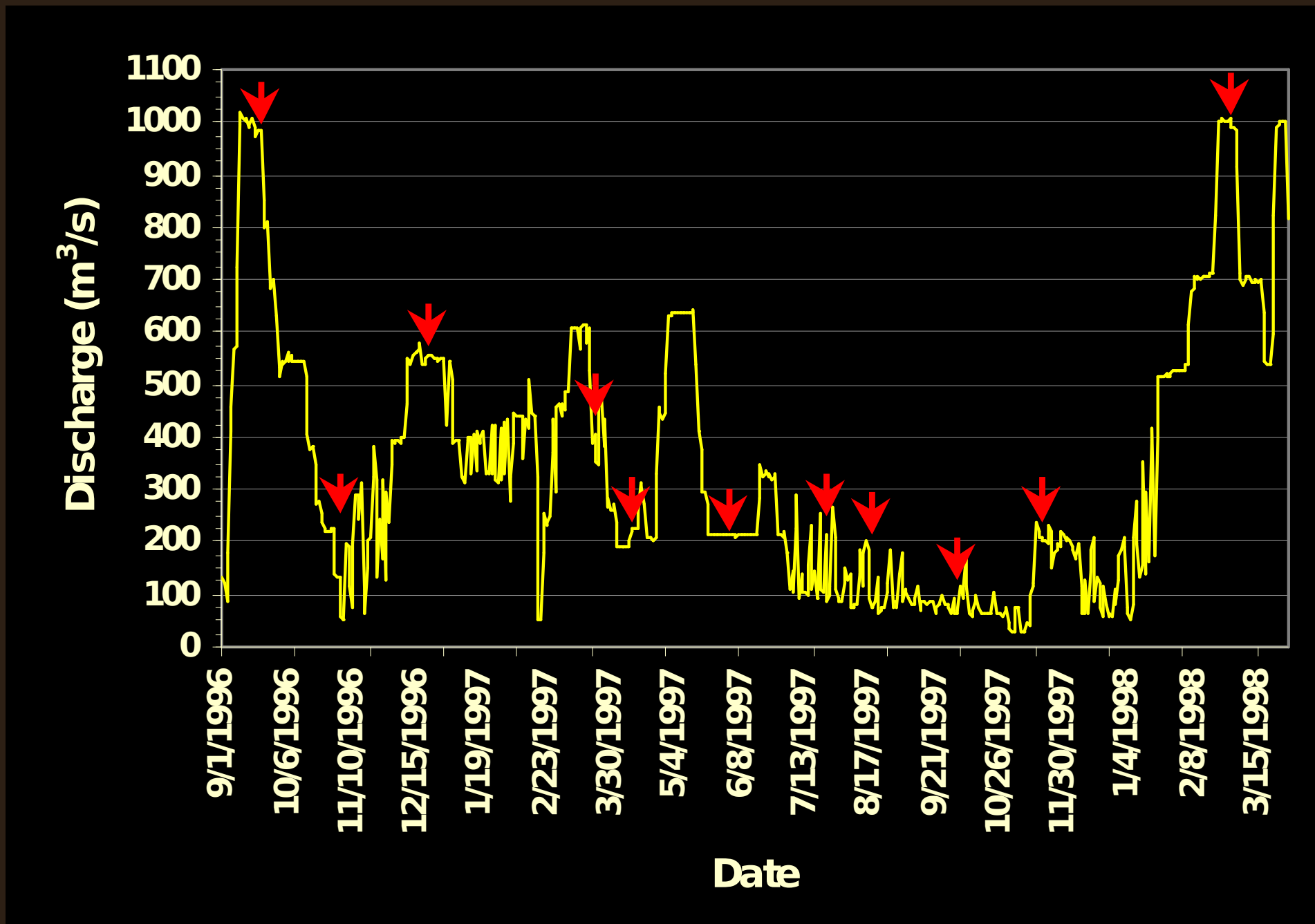
An obvious example:

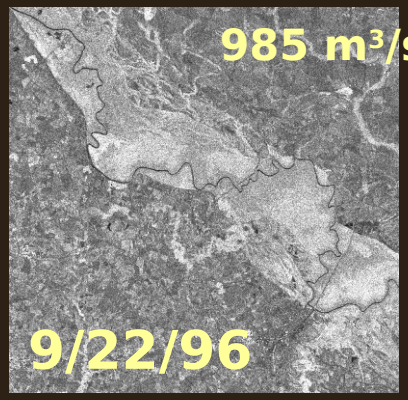


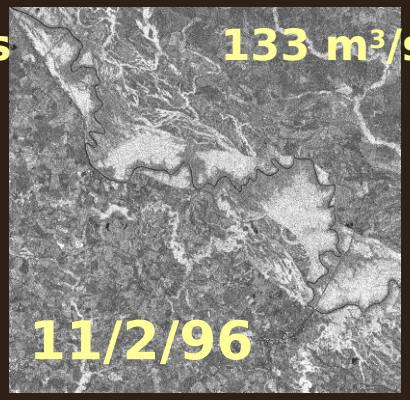


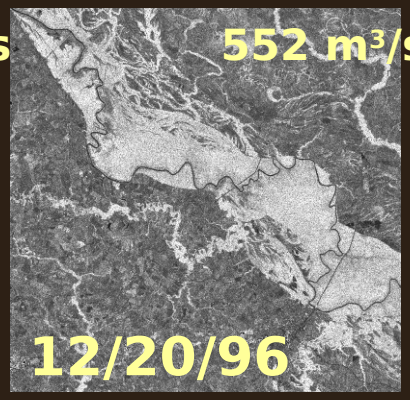
December 20, 1996: 19,600 cfs March 26, 1997: 14,160 cfs

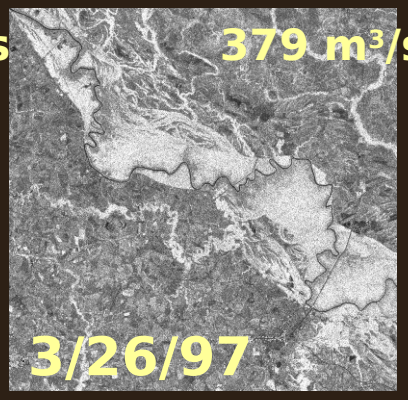
- But, such subtle differences are not always appa
  using existing elevation data

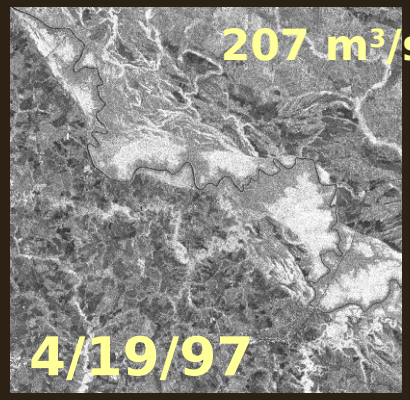

Discharge (m3/s)
1100
1000
900
800
700
600
500
400
300
200
100
0
9/1/1996
10/6/1996
11/10/1996
12/15/1996
1/19/1997
2/23/1997
3/30/1997
5/4/1997
6/8/1997
7/13/1997
8/17/1997
9/21/1997
10/26/1997
11/30/1997
1/4/1998
2/8/1998
3/15/1998
Date

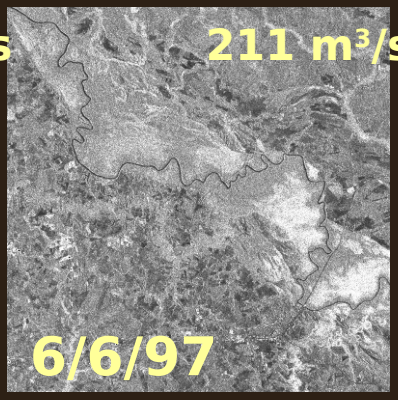

985 m³/s
9/22/96

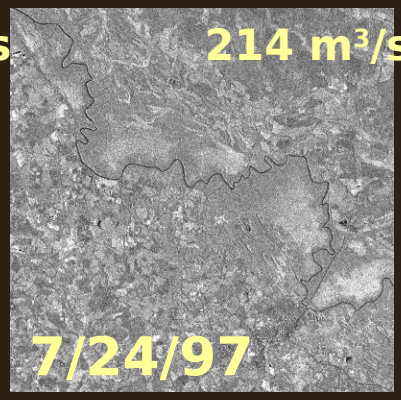

133 m³/s
11/2/96

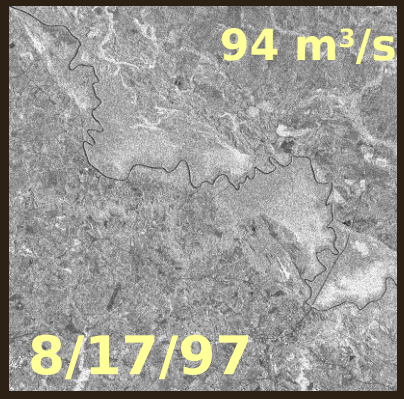

552 m³/s
12/20/96

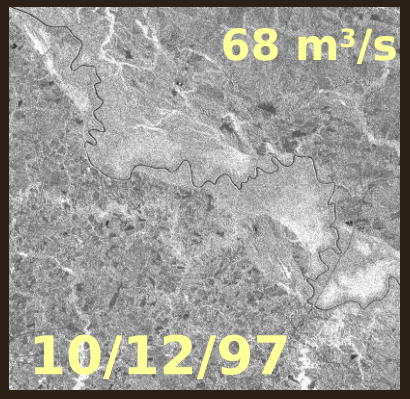

379 m³/s
3/26/97

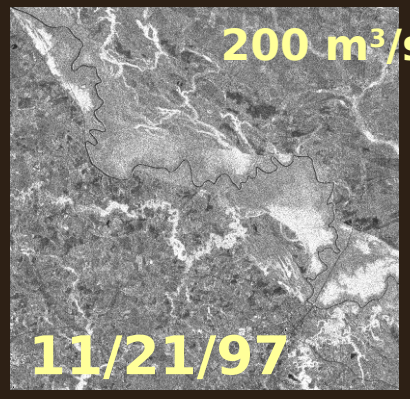

207 m³/s
4/19/97

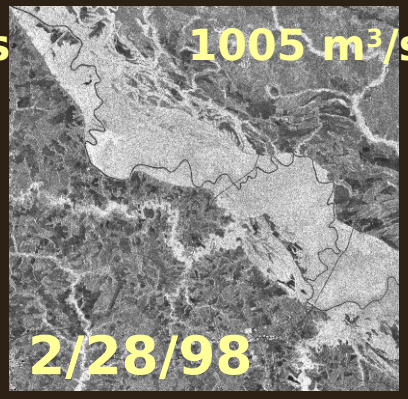

211 m³/s
6/6/97


214 m³/s
7/24/97


94 m³/s
8/17/97


68 m³/s
10/12/97


200 m³/s
11/21/97

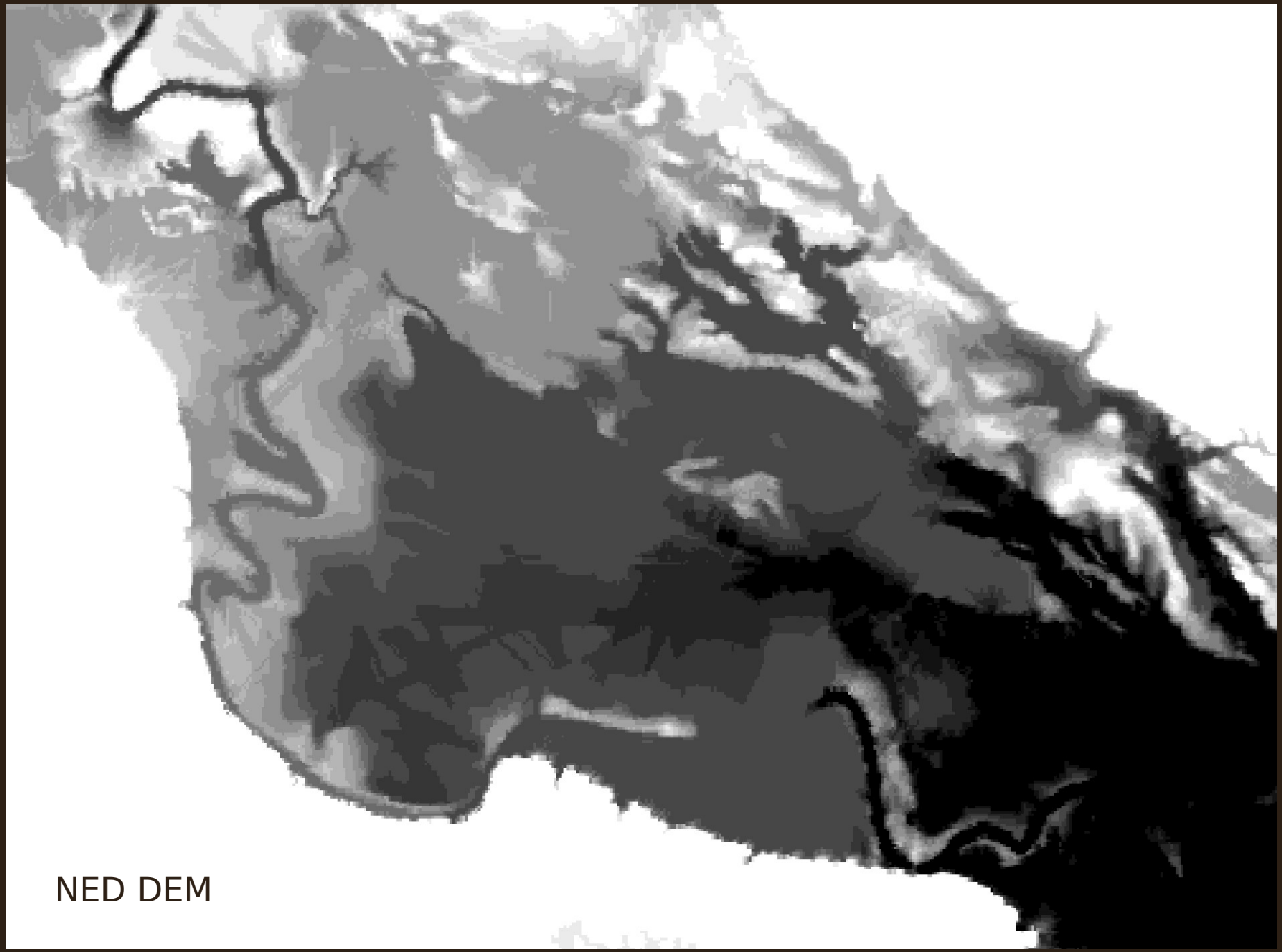

1005 m³/s
2/28/98

Mapping Flooding

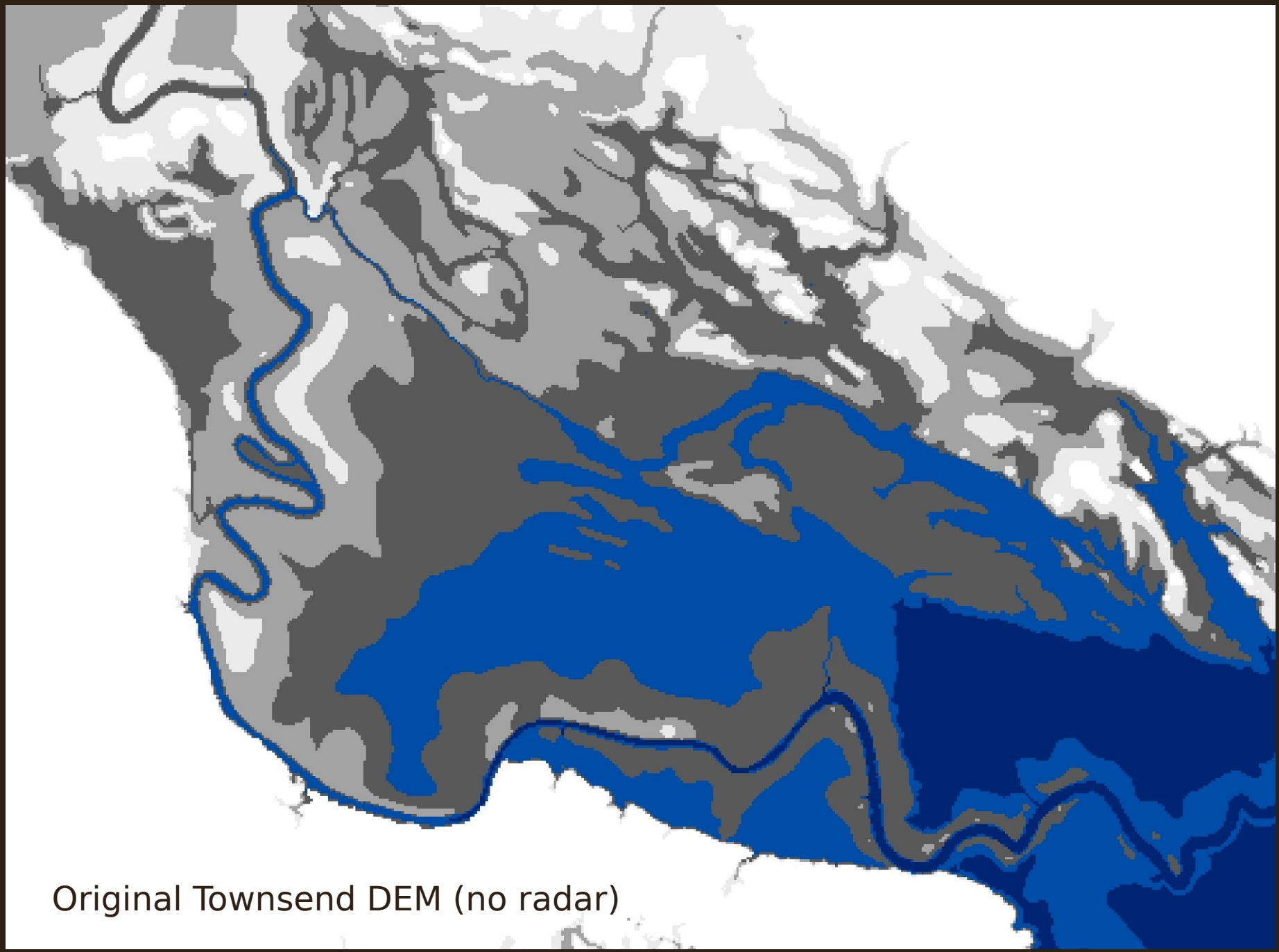
- Use a decision tree model (statistical technique) to select the backscatter threshold at which you distinguish flooded from non-flooded
- Photogr. Eng. & Rem Sens. Paper (2001)
  - Validate using floodplain gages
  - Leaf-off accuracy = 98.1%
  - Leaf-on accuracy = 89.1%
  - Modeling will focus on use of leaf-off imagery

Creating the DEM and Flood Model

- Backtrack a bit.....



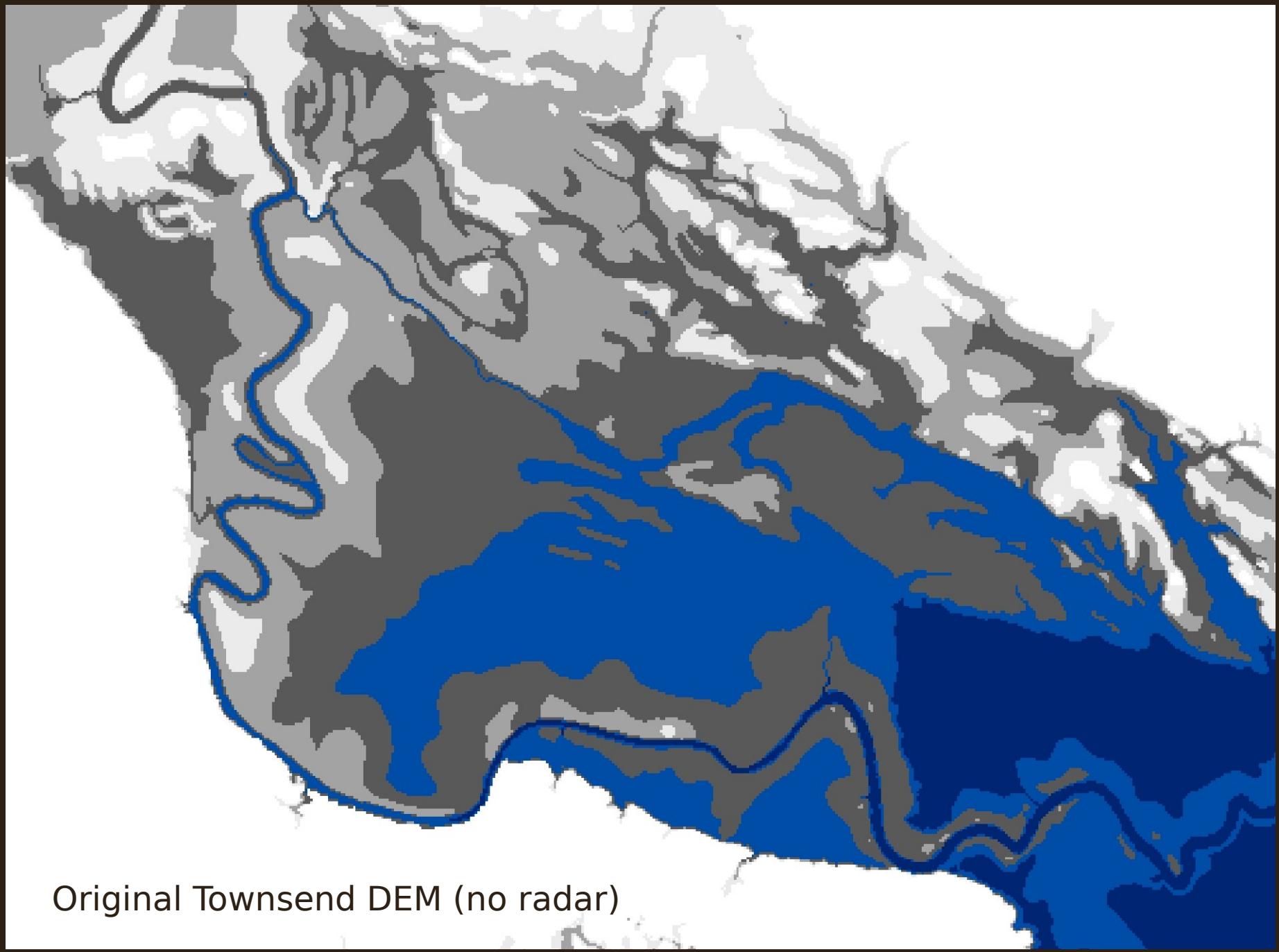
NED DEM



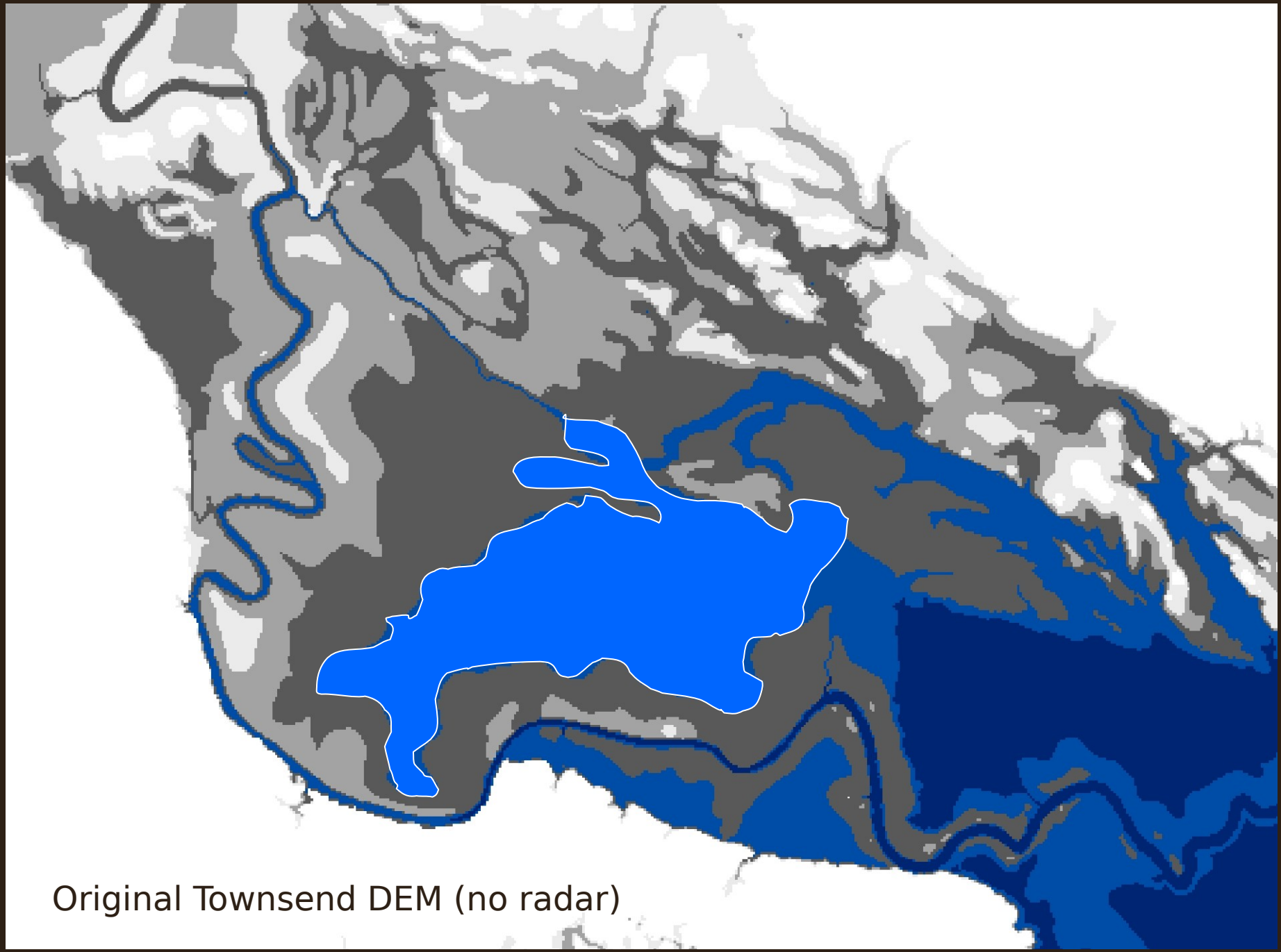
Original Townsend DEM (no radar)

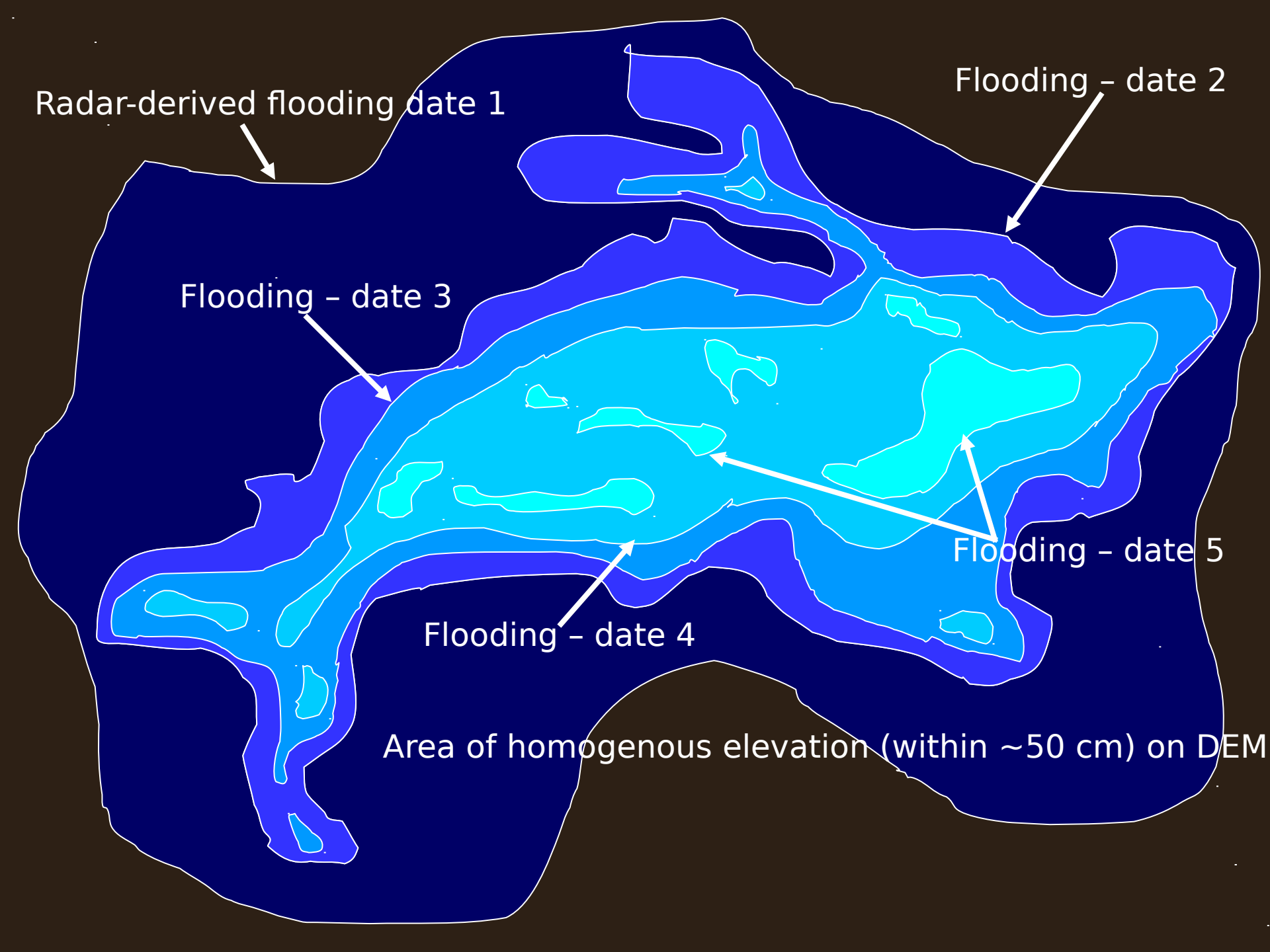
How do you use radar to improve the DEM?

- Radar images taken at multiple dates represent flooding under different flow conditions
- For a contiguous patch of elevation (see previous slide), differences in flooding between dates are due to small differences in elevation



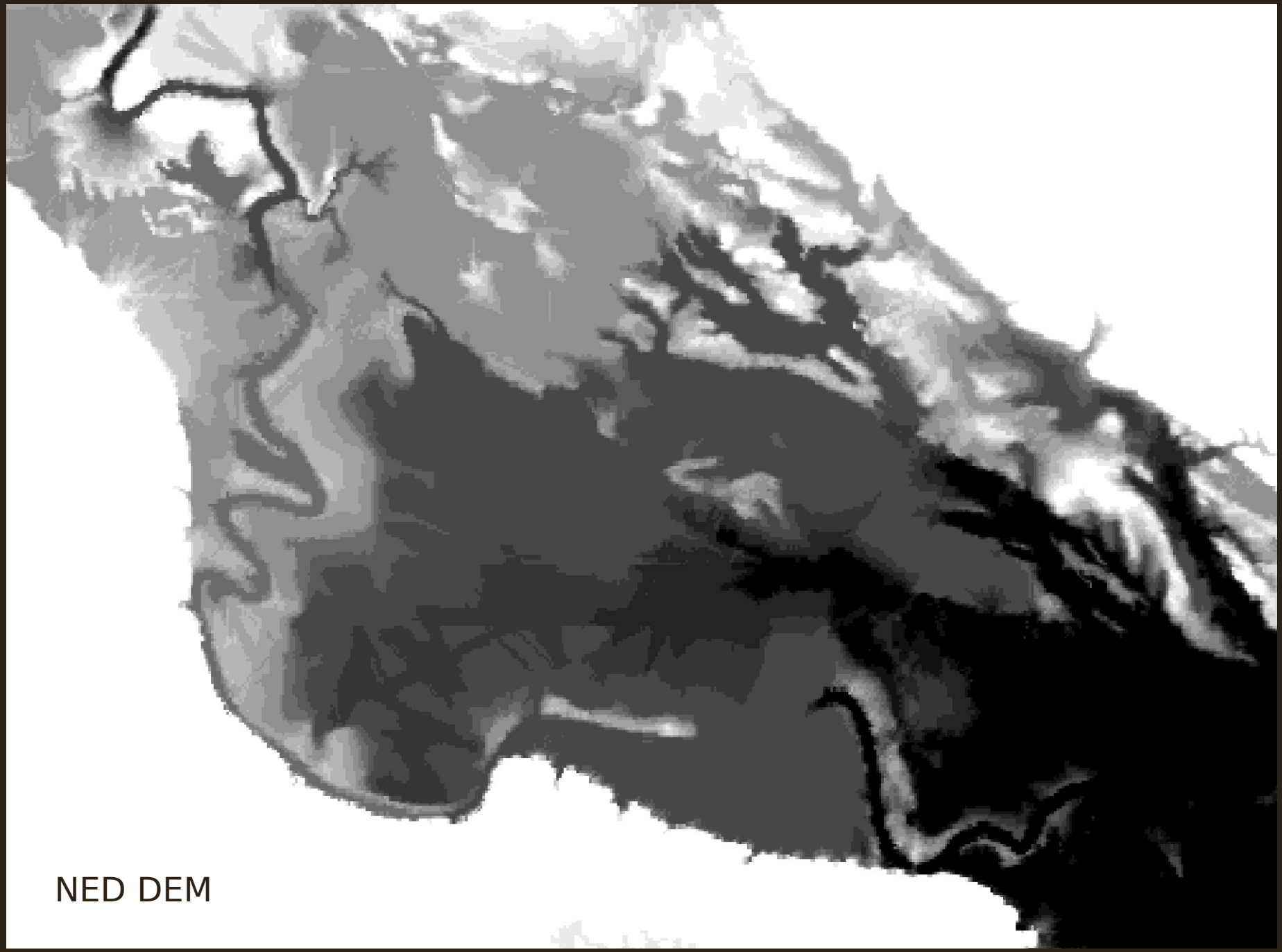
Original Townsend DEM (no radar)


Original Townsend DEM (no radar)

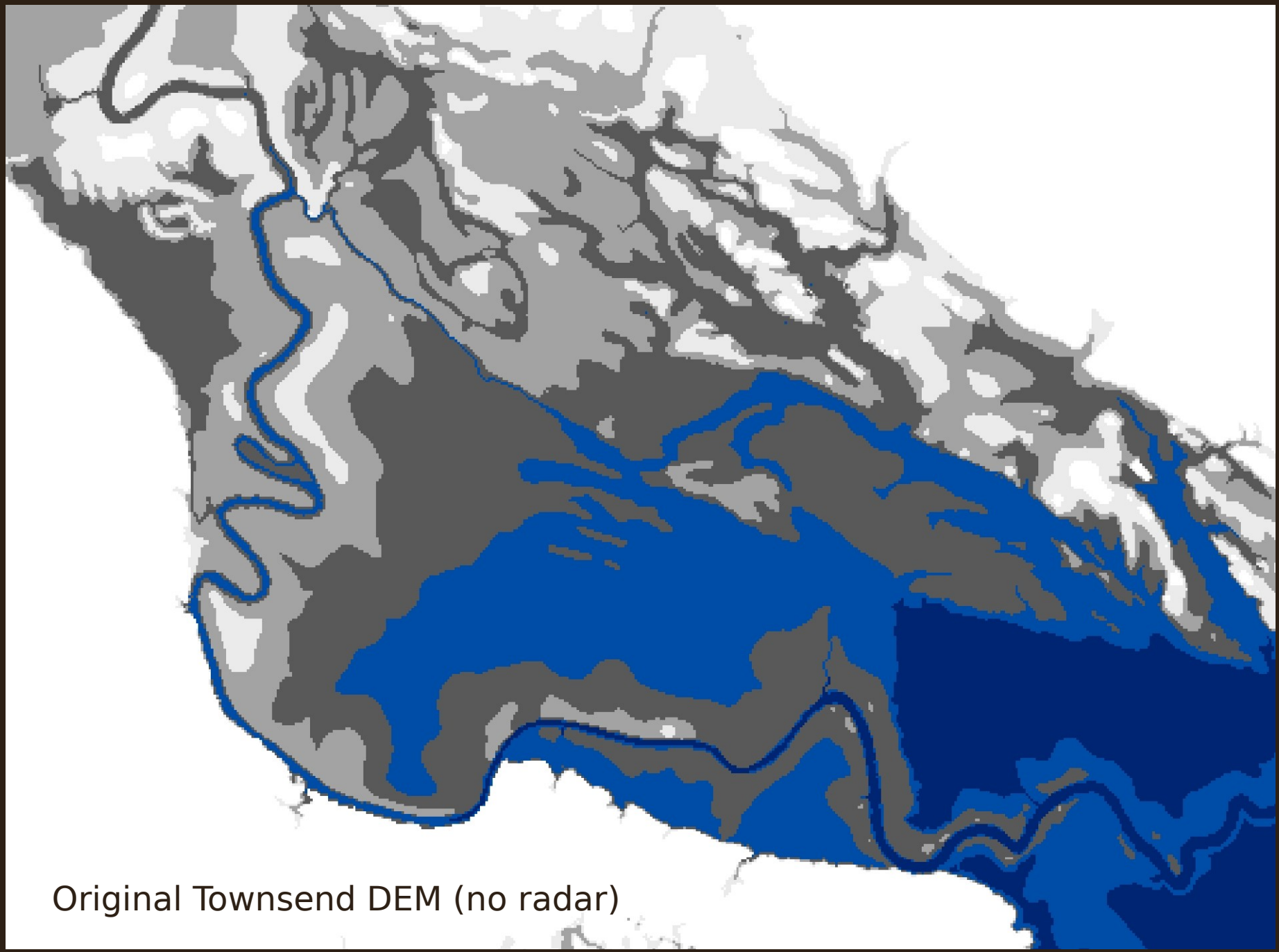

Radar-derived flooding date 1
Flooding – date 2
Flooding – date 3
Flooding – date 5
Flooding – date 4
Area of homogenous elevation (within ~50 cm) on DEM

To improve elevation estimates

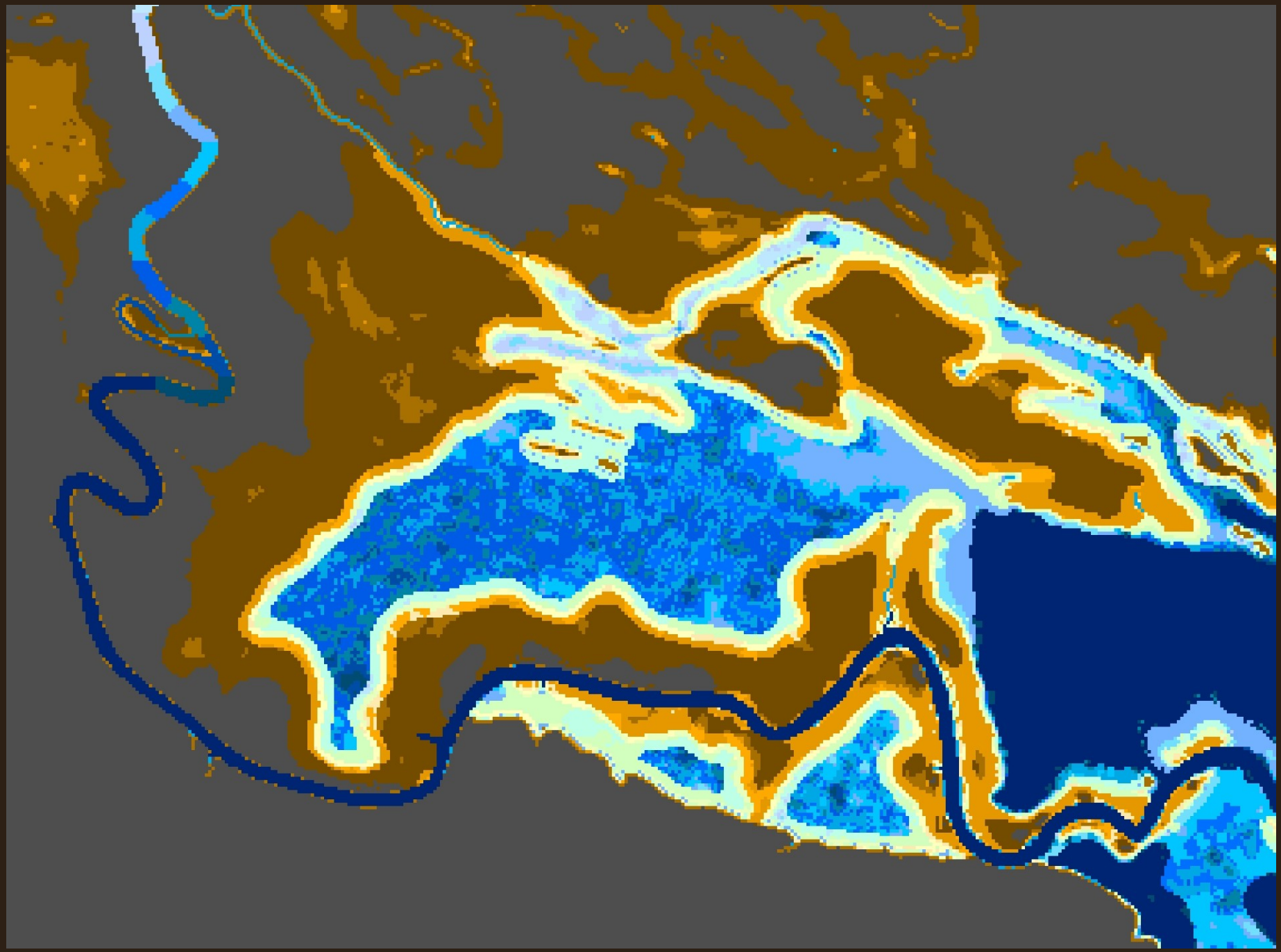
- Use standard GIS interpolation algorithms to create continuous elevations between each flood zone
- Use gage data to identify differences in elevation
- Generate improved DEM
- Key: 21 radar images are used, which provides a lot of added topographic detail



NED DEM



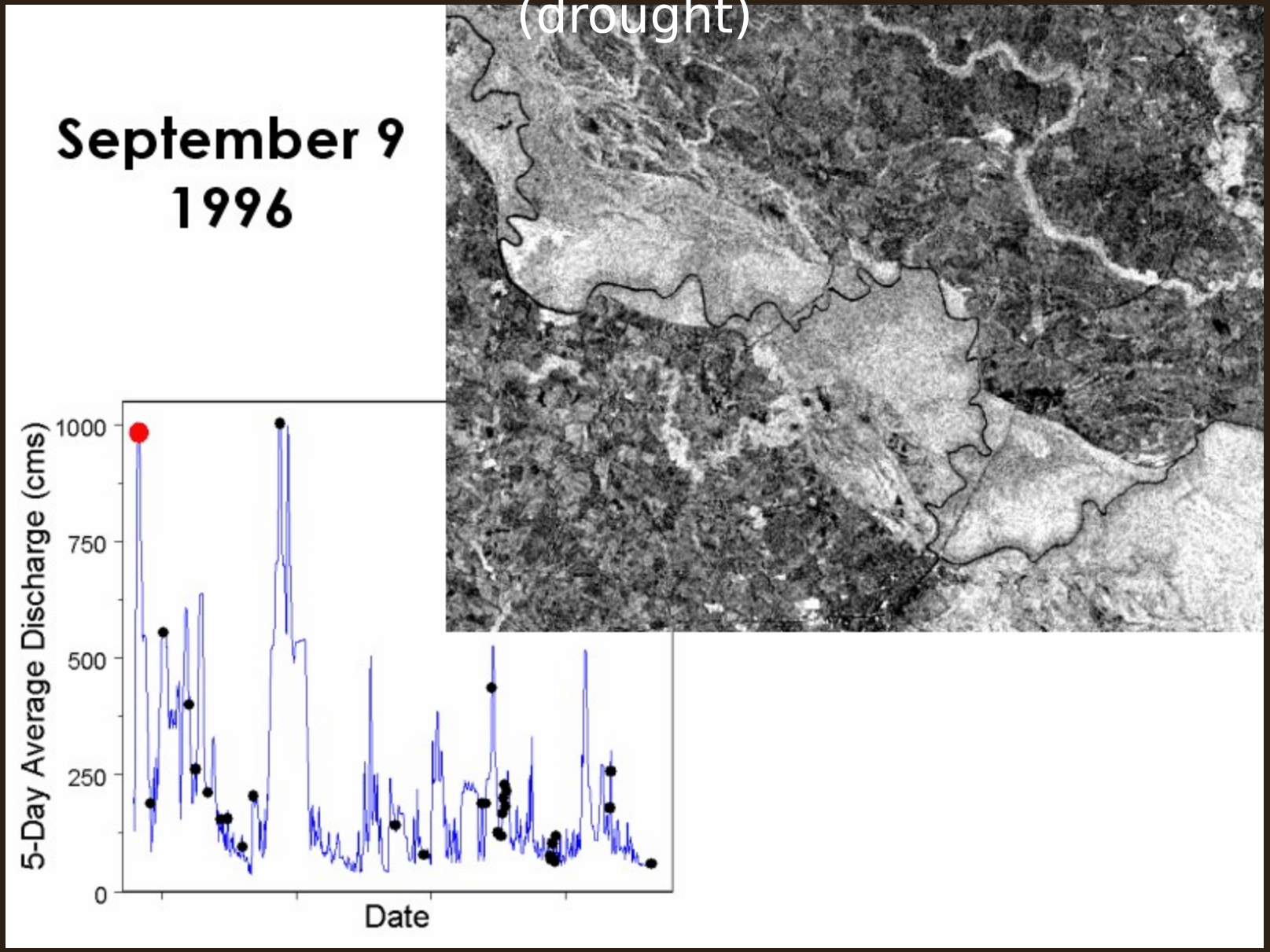
Original Townsend DEM (no radar)



The flood inundation model

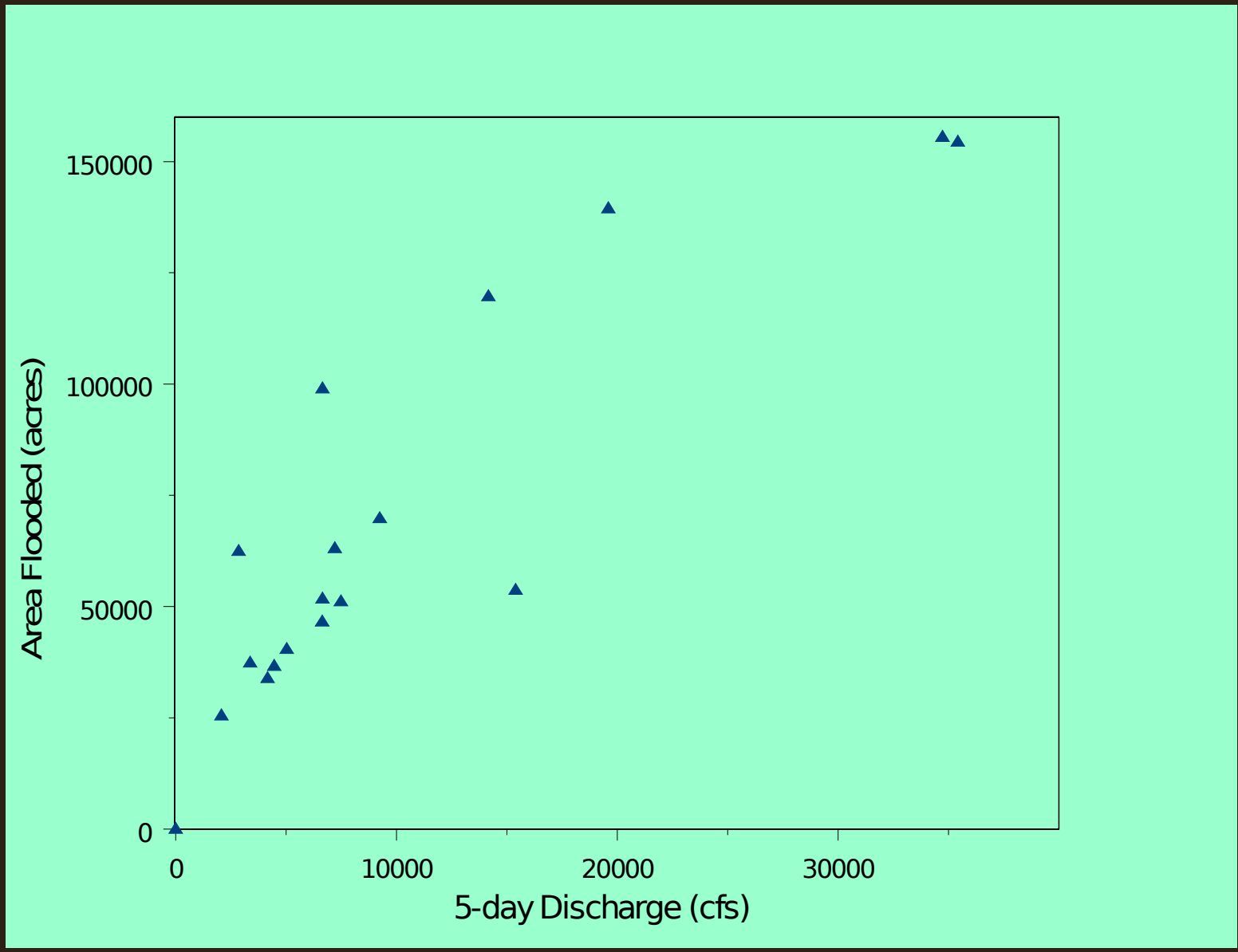
- Actually starts with the radar data and not the DEM (radar is accurate on flooding extent)
- Uses the DEM to interpolate between RADAR dates
- Uses DEM to identify depth of flooding

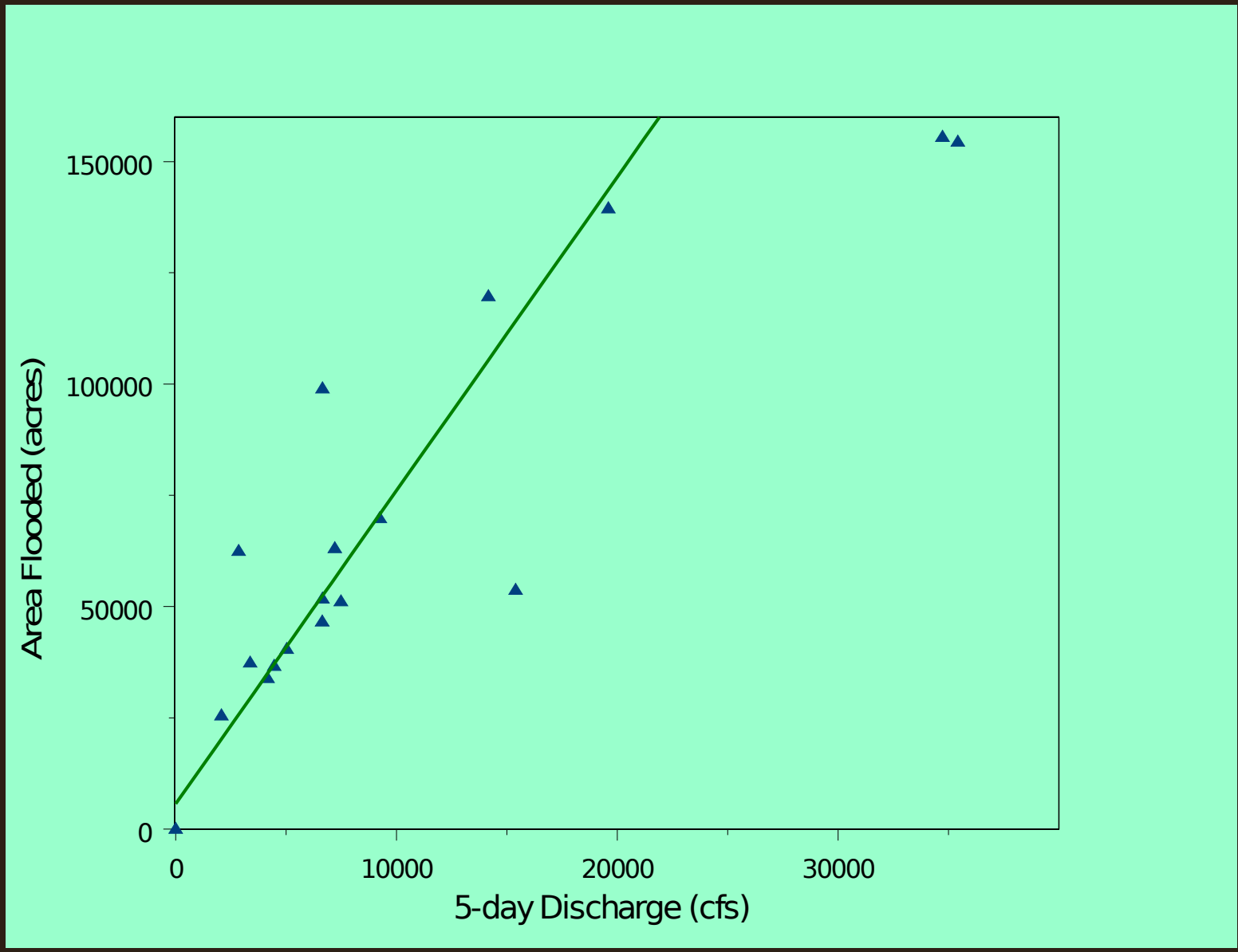
Repeat SAR imaging ran from September 1996 (Hurricane Fran) to December 2001 (drought)

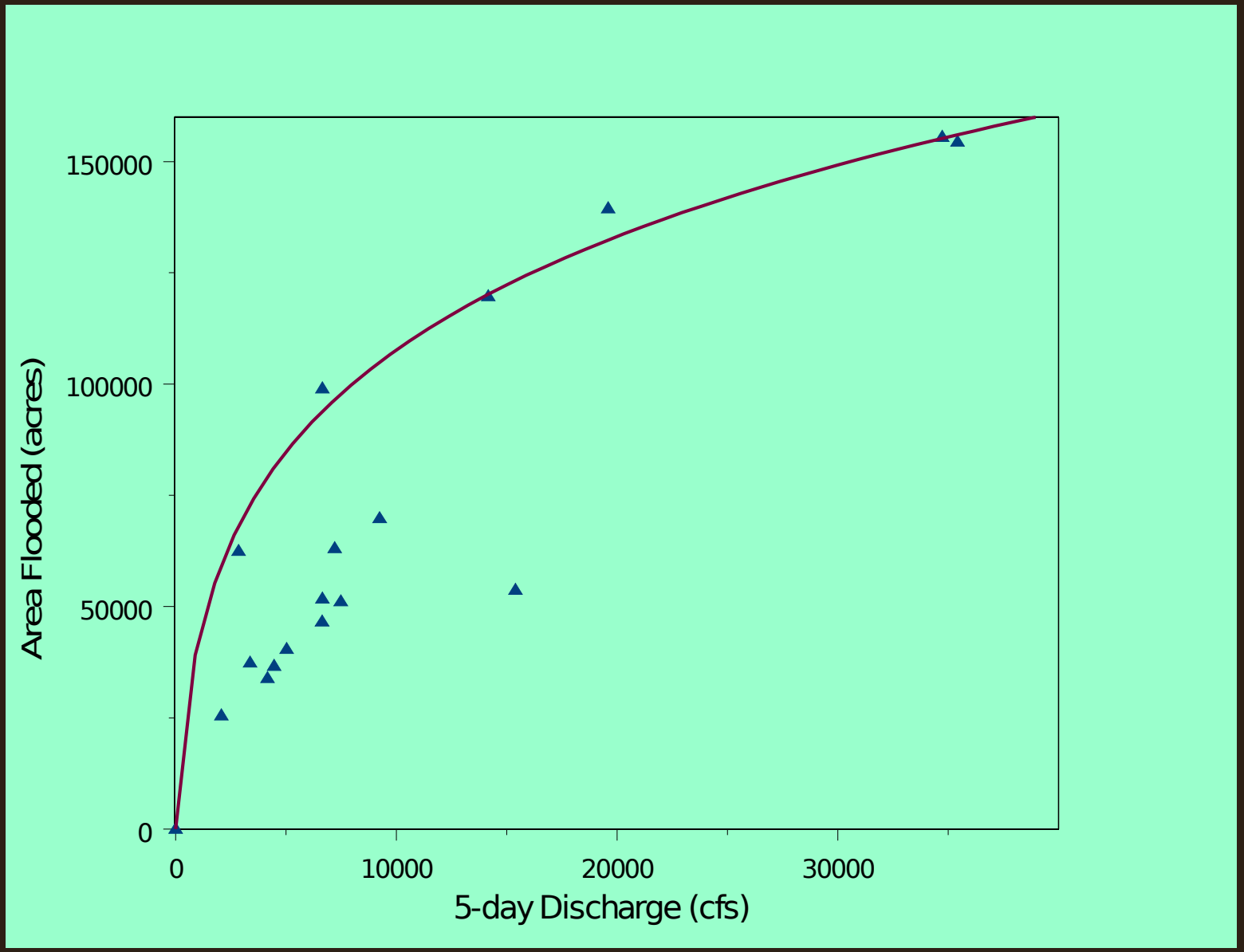


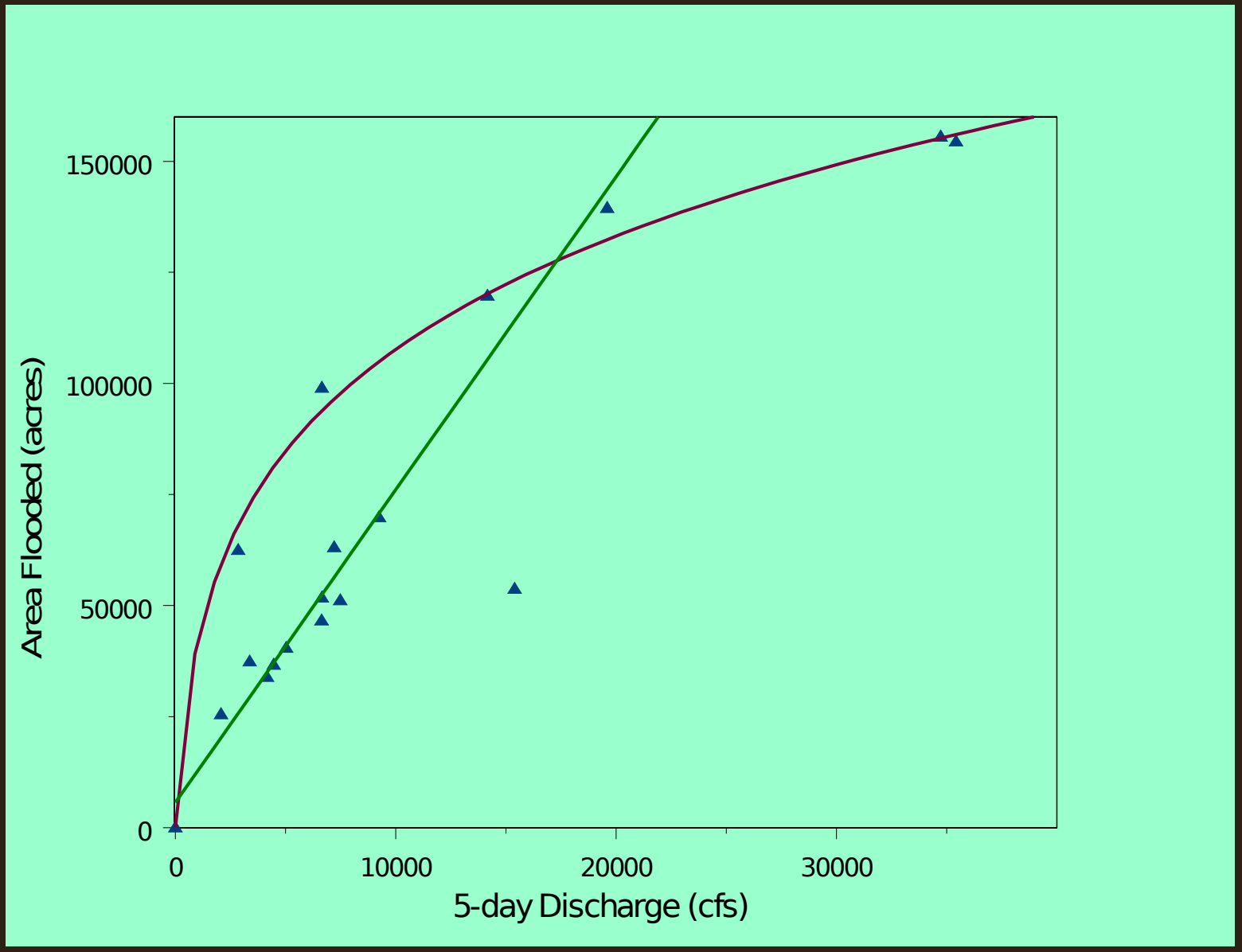
From each date:

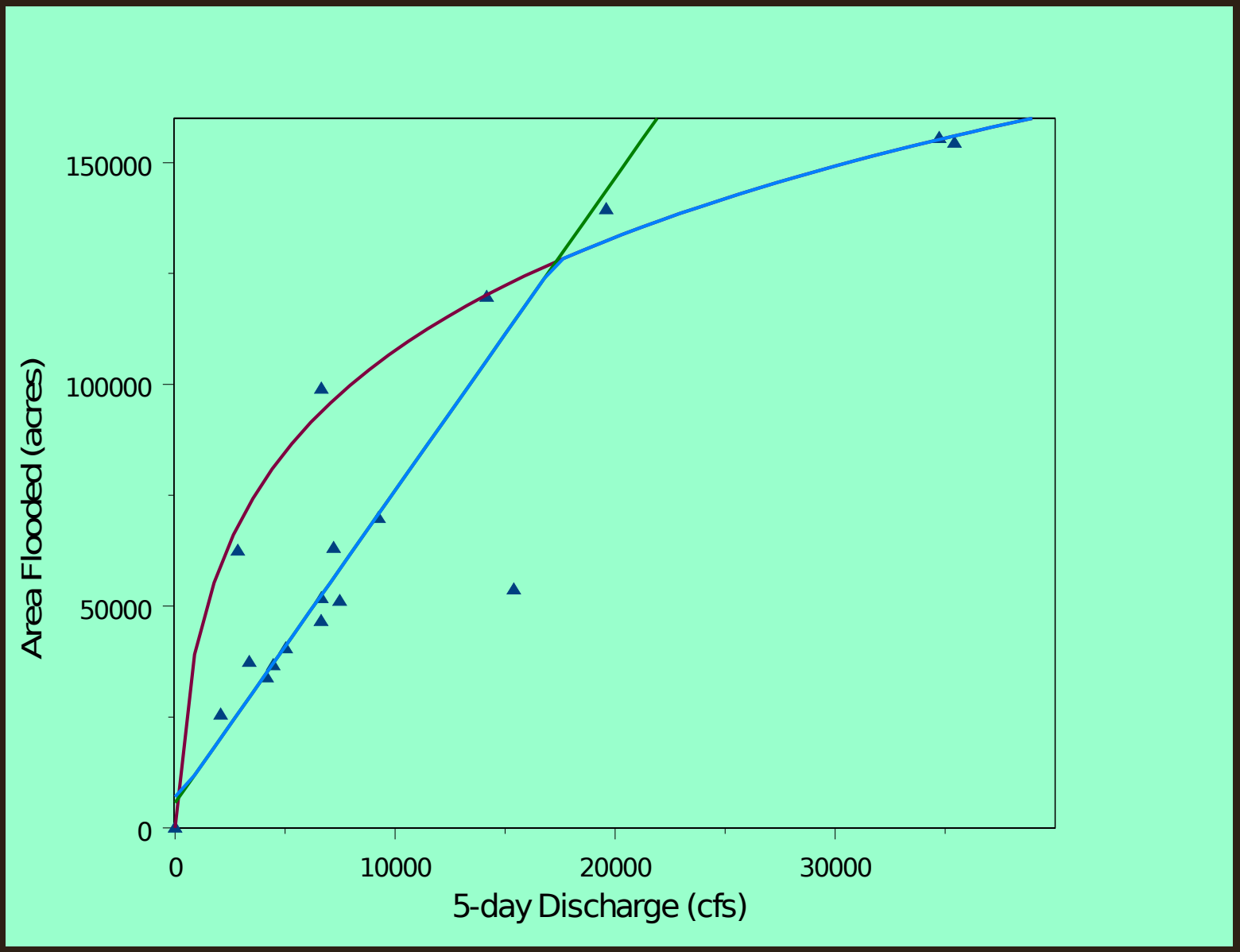
- We can calculate the amount of area flooded based on radar
- We know the discharge from the Roanoke Rapids dam (which is the primary control on flooding)
- We can develop a relationship of:
  - AREA FLOODED = f(5-day DISCHARGE)

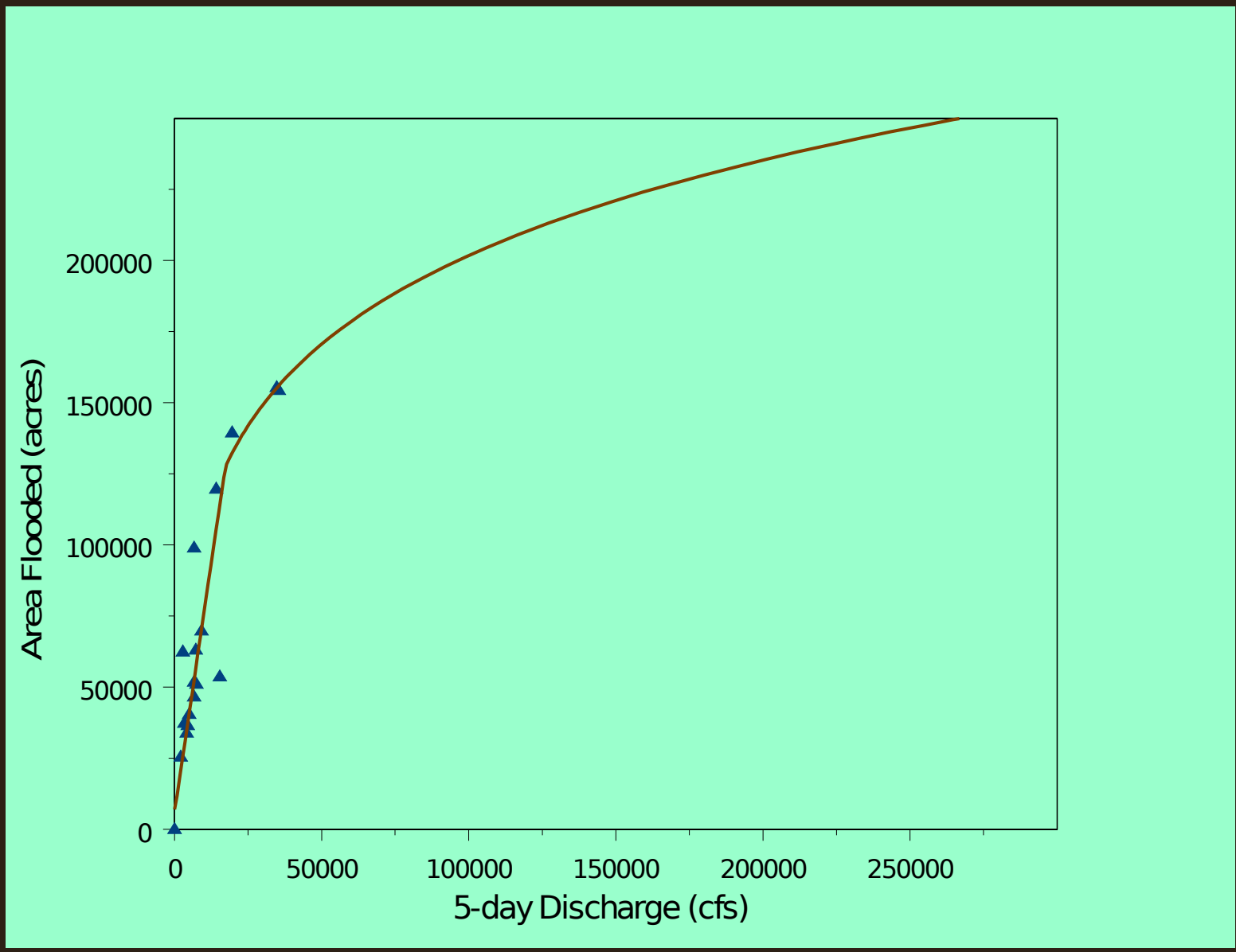

150000
100000
50000
0
Area Flooded (acres)
0
10000
20000
30000
5-day Discharge (cfs)


150000
100000
50000
0
Area Flooded (acres)
0
10000
20000
30000
5-day Discharge (cfs)


150000
100000
50000
0
Area Flooded (acres)
0
10000
20000
30000
5-day Discharge (cfs)

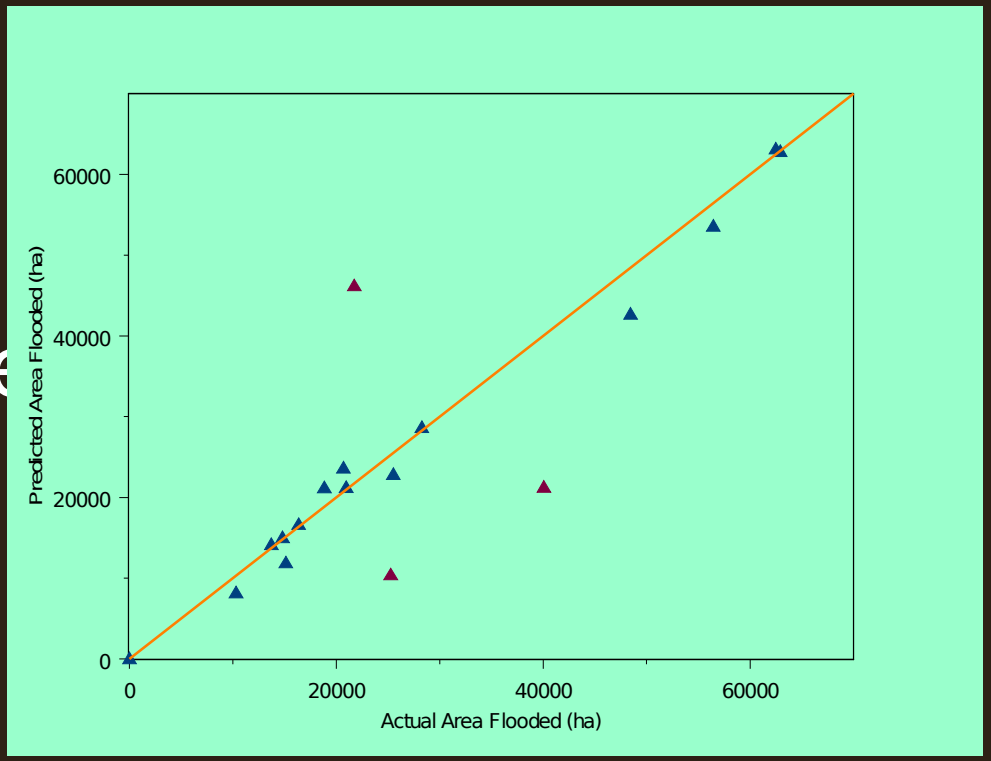

150000
100000
50000
0
Area Flooded (acres)
0
10000
20000
30000
5-day Discharge (cfs)


150000
100000
50000
0
Area Flooded (acres)
0
10000
20000
30000
5-day Discharge (cfs)


Area Flooded (acres)
0
50000
100000
150000
200000
0
50000
100000
150000
200000
250000
5-day Discharge (cfs)

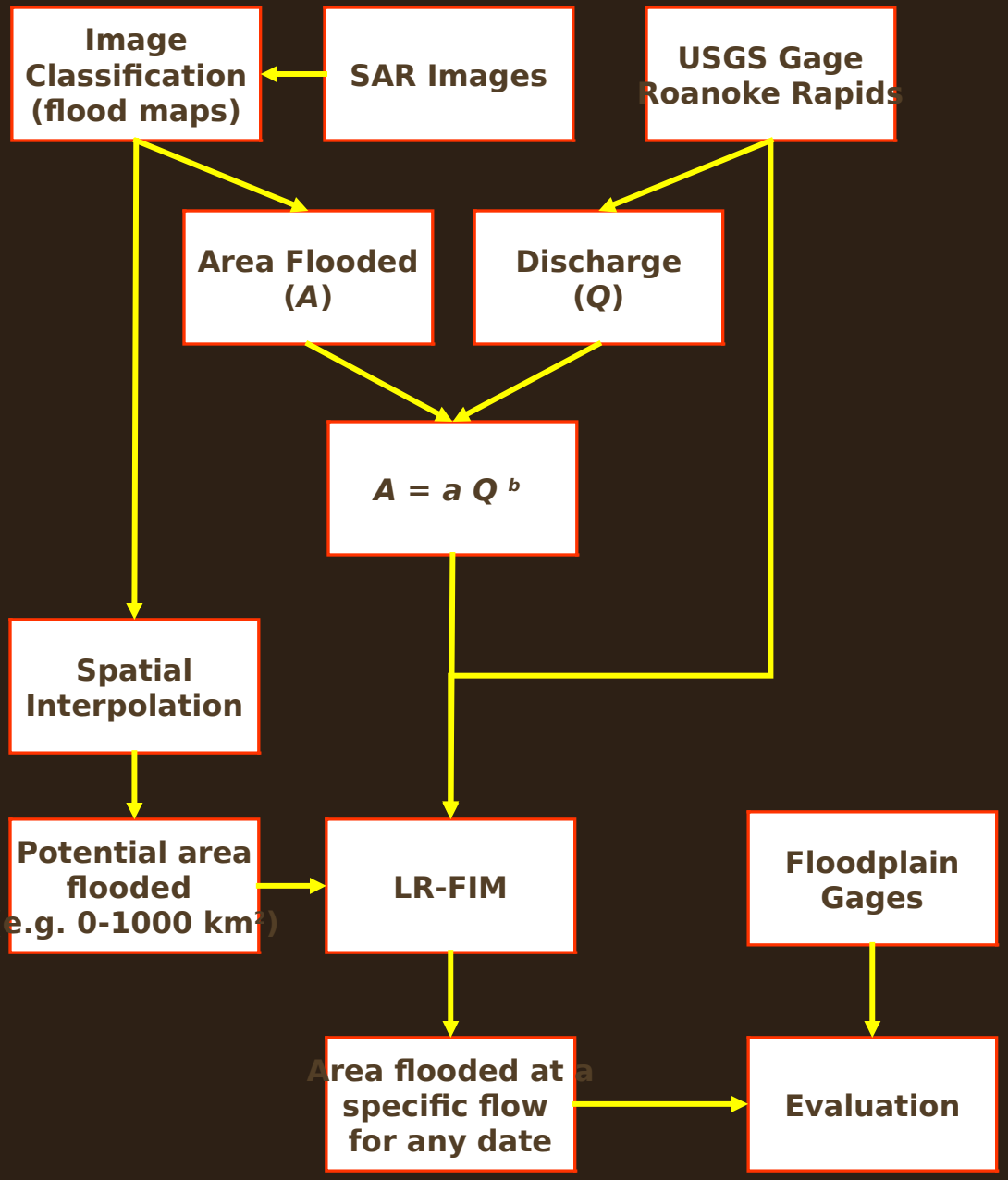
Statistical Model Output

- Linear model
  - $R^2 = 0.972$
  - MAE = 1898 ha
- Exponential mode
  - $R^2 = 0.994$
  - MAE = 1166 ha
- Merged model
  - $R^2 = 0.985$
  - MAE = 1350 ha



Next....

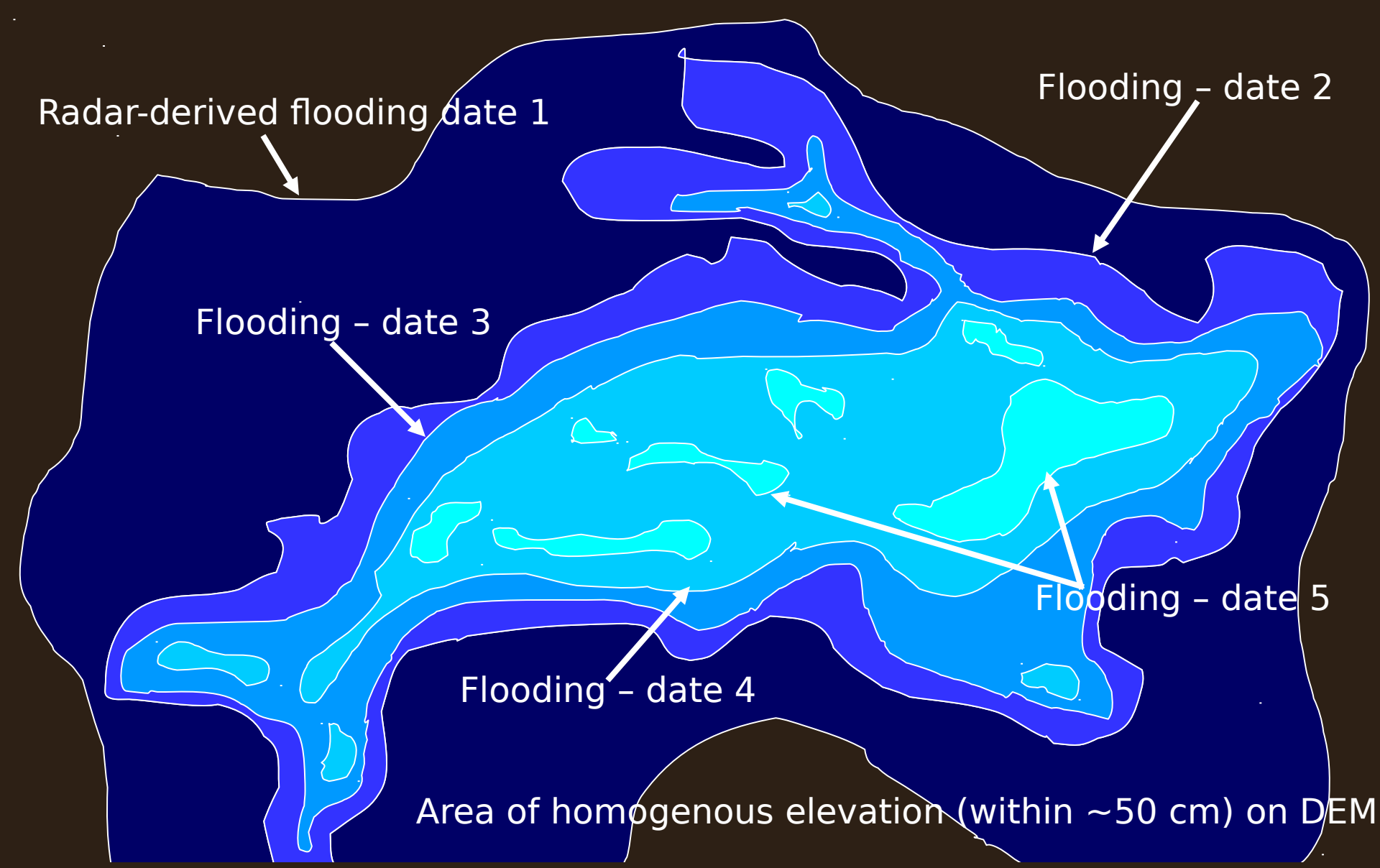
- How do we build a spatially explicit model of flood extent?



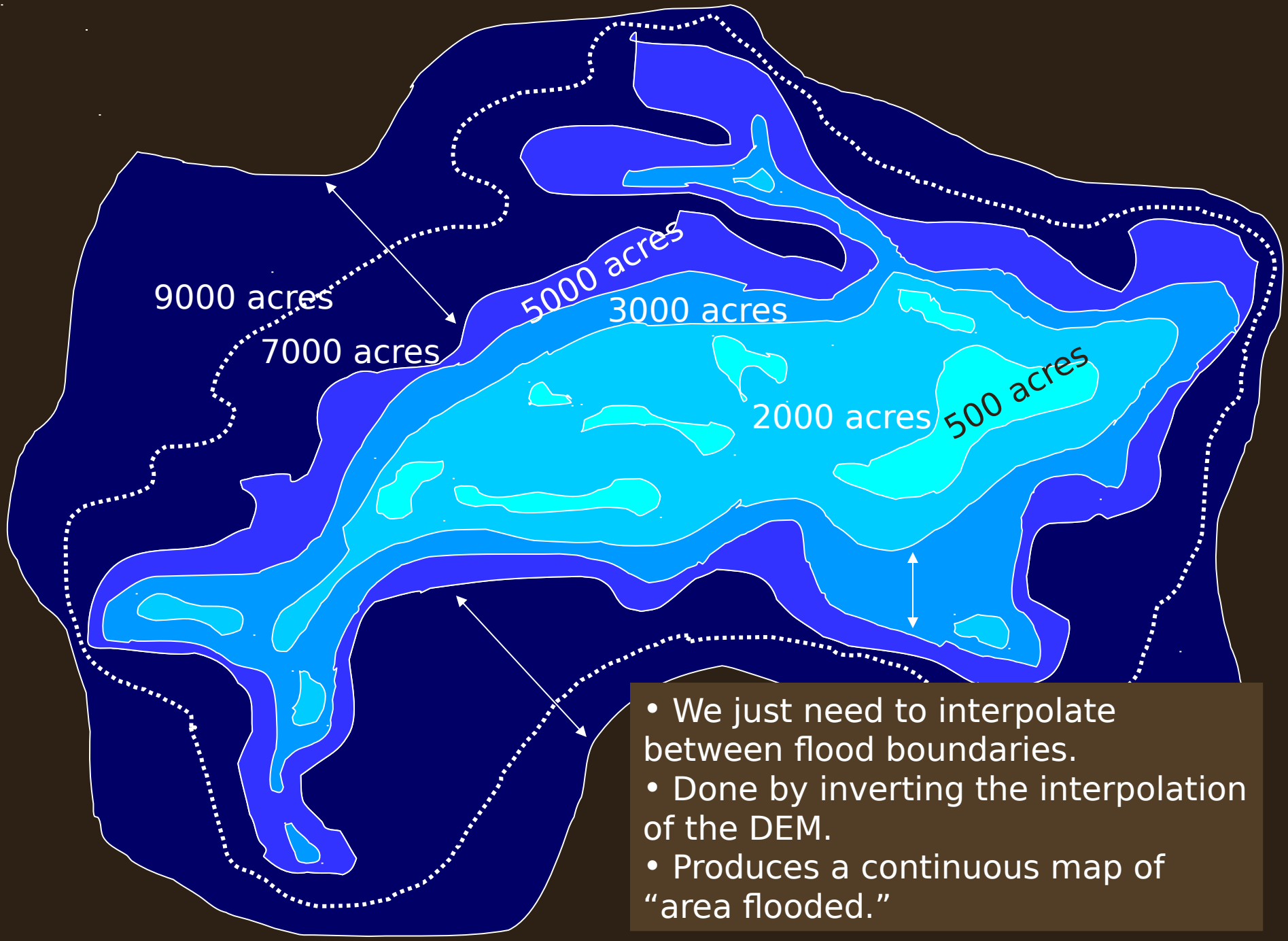
LR-FIM: Lower Roanoke – Flood Inundation Model

All we need is....

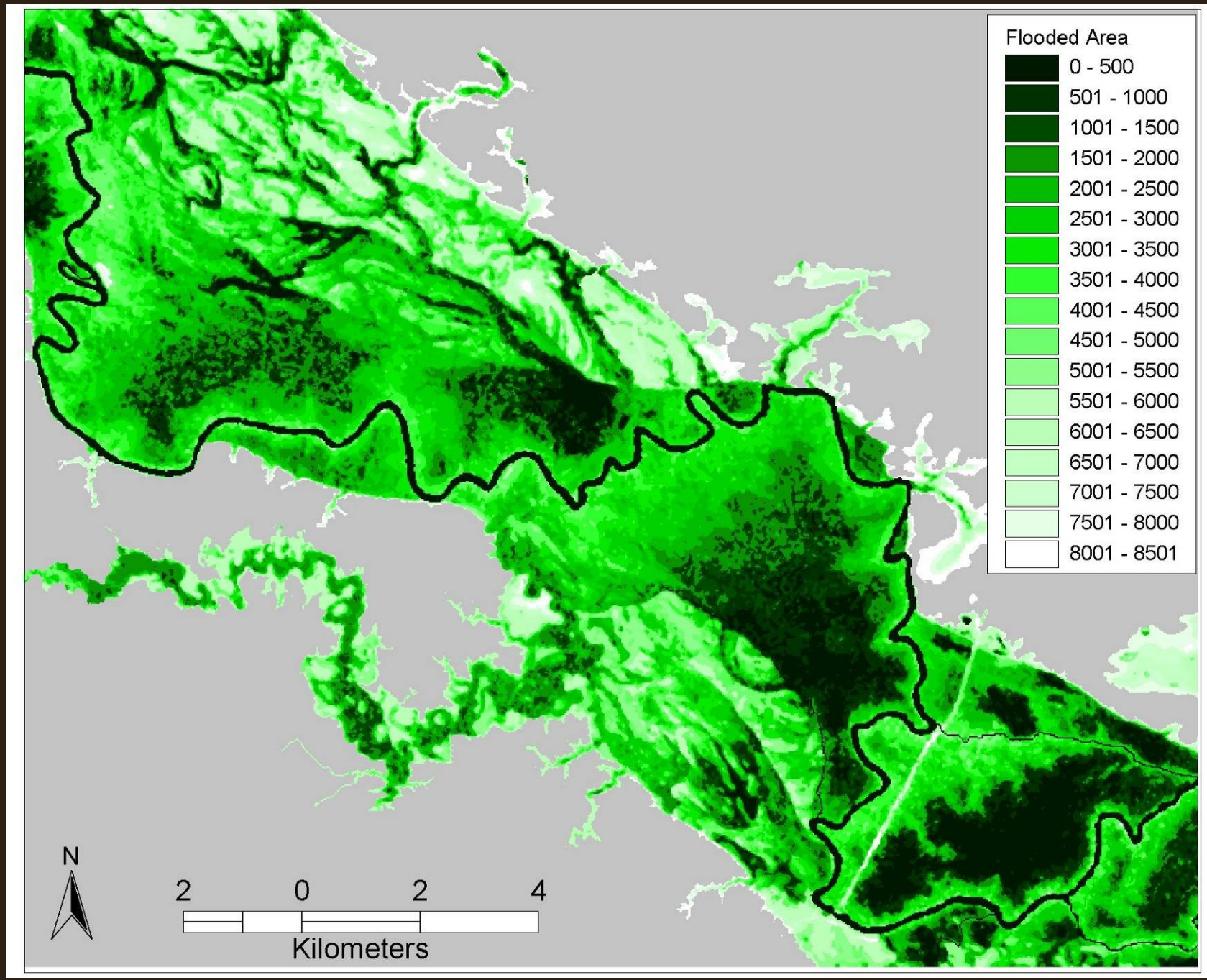
- Area flooded = f(discharge)
- Discharge comes from the HydroLogics team
- All we need is some representation of area
  - It turns out this is easy to do!


Radar-derived flooding date 1
Flooding – date 2
Flooding – date 3
Flooding – date 5
Flooding – date 4
Area of homogenous elevation (within ~50 cm) on DEM

Remember we have already mapped flooded area for each of 31 radar dates!



- We just need to interpolate between flood boundaries.
- Done by inverting the interpolation of the DEM.
- Produces a continuous map of “area flooded.”


Flooded Area
0 - 500
501 - 1000
1001 - 1500
1501 - 2000
2001 - 2500
2501 - 3000
3001 - 3500
3501 - 4000
4001 - 4500
4501 - 5000
5001 - 5500
5501 - 6000
6001 - 6500
6501 - 7000
7001 - 7500
7501 - 8000
8001 - 8501
N
2 0 2 4
Kilometers

Area Flooded

- Looks like a digital elevation model
- Actually is a representation of the area that would be flooded at a given discharge
- This is then used to simulate flood extent

Evaluation of the spatial model

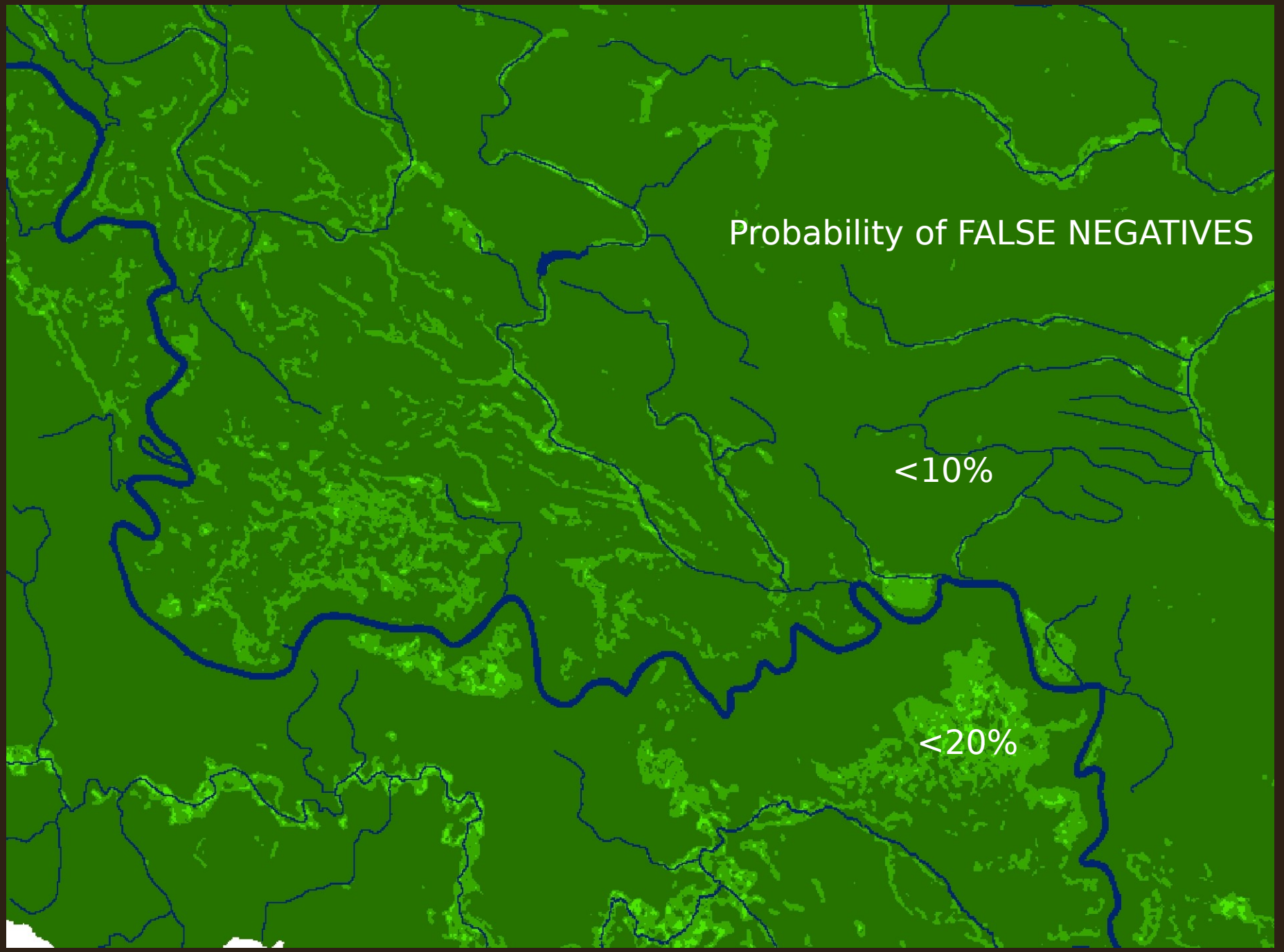
- Reported in Townsend & Foster (2003) in *Water Resources Research*
- Compare with floodplain gages for the period 1996-2001
  - On a day by day basis, the model was correct on its predictions 87.8% of the time, BUT:
- Looking at total duration of flooding (hydroperiod):
  - The model got the correct duration of flooding 97.5% of the time

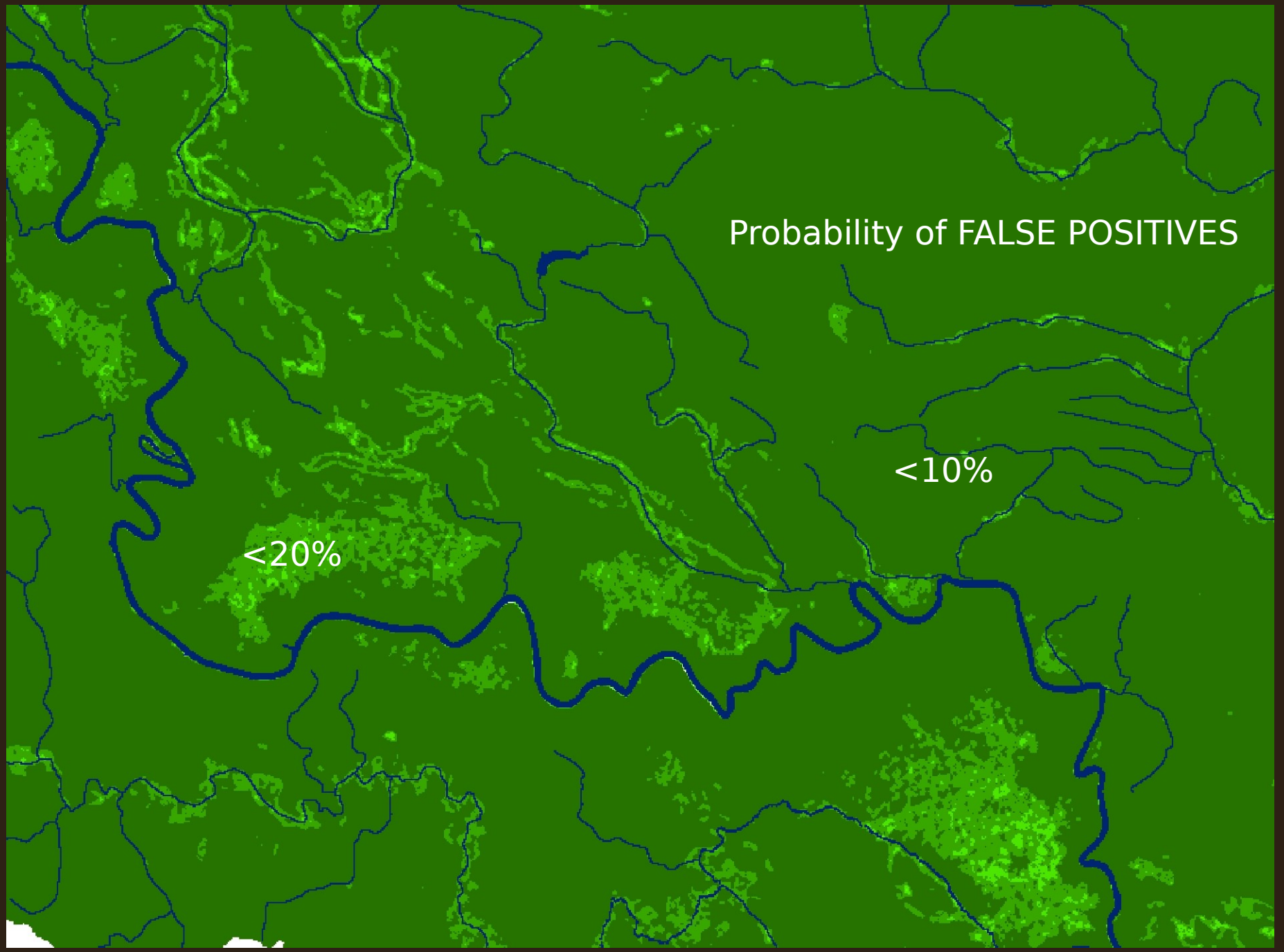
Model Evaluation

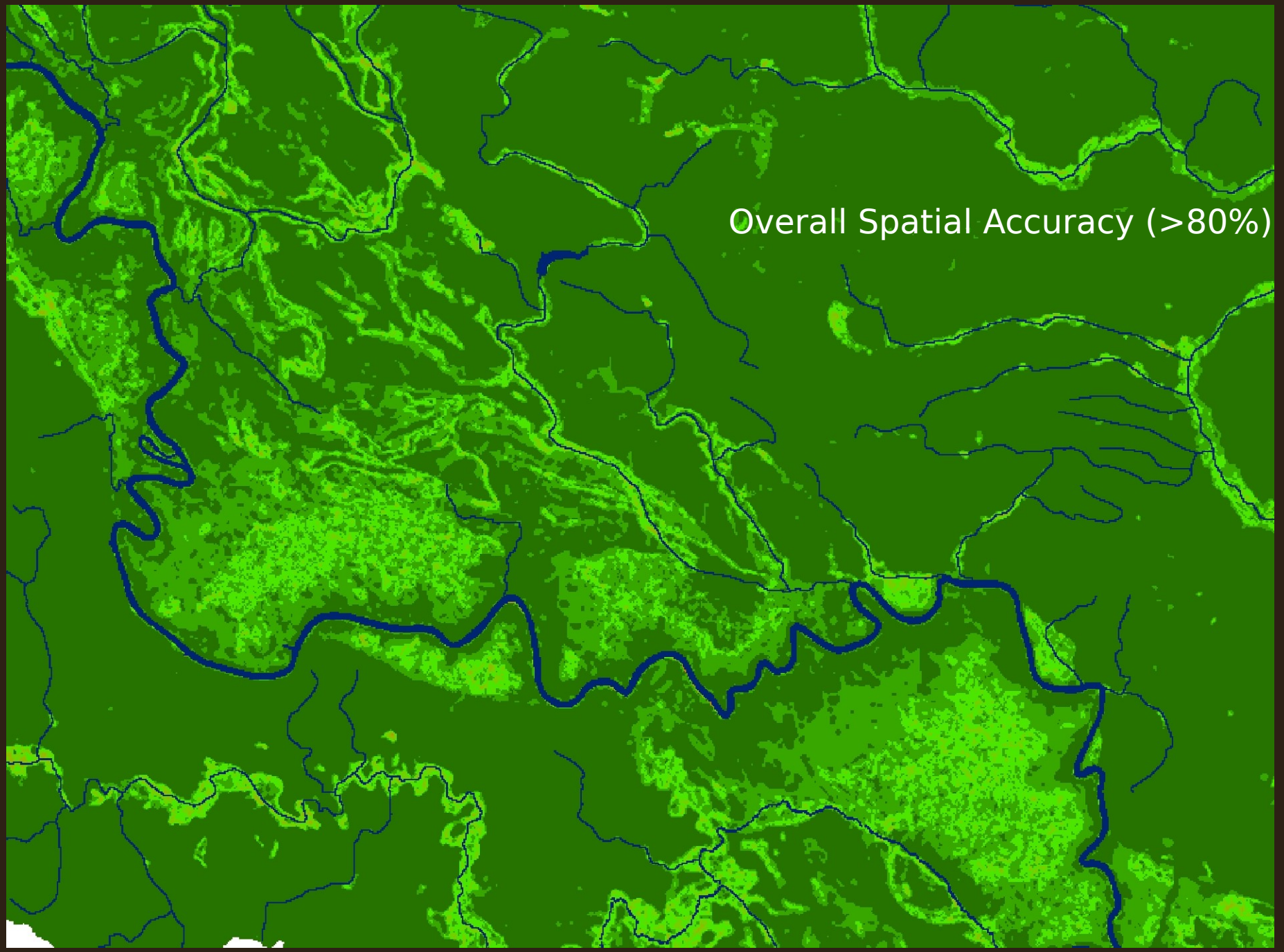
- The model may be off by 1-2 days on the rising and falling limbs of floods, but duration is very accurate.
- The largest source of error was Hurricane Floyd, which occurred in the middle of the test period
- Specifically, Floyd dumped >20 inches of rainfall that is not represented in the discharge data
- Day-by-day flooding improved from 87.8% to 94% without Floyd
- The model has no rainfall input (e.g., from NEXRAD)
  - This would be an improvement that would capture those floods that are enhanced by local heavy rainfall
  - Likely a very infrequent necessity

Spatial Evaluation

- Which areas had the largest errors when simulating just the dates with radar images?


Probability of FALSE NEGATIVES
<10%
<20%


Probability of FALSE POSITIVES
<10%
<20%


Overall Spatial Accuracy (>80%)

Flood Depth

- Straightforward process
- Flood extent is needed first
  - Depth of flooding is not a linear function of river mile
  - Human modifications to floodplain (flood model gets actual flooded area)
- Simple linear model of river stage at the twelve river gages from Weldon to Plymouth
- Water is moved into floodplain along topographically controlled flow gradients (from DEM)
- All that is required is predictions of river stage from HydroLogics

All you really need to know:

- Flow paths (from DEM)
- Which river gage is associated with a given pixel
- Actually, unless the location is right at a river gage, you need to know which two river gages are closest
- Then, scale the flood elevation between the two

Evaluation

- Again, simulate the period of record and compare against floodplain gages
- Average RMSE

Big Swash 1: 15.6 cm
Big Swash 2: 42.0 cm
Big Swash 3: 54.0 cm
Broadneck 1: 29.5 cm
Broadneck 2: 9.4 cm
Broadneck 3: 19.1 cm
Devils Gut 1: 8.7 cm
Devils Gut 2: 9.0 cm
Devils Gut 3: 11.0 cm
Cow Creek 2: 8.0 cm
Cow Creek 3: 7.5 cm
Cow Creek 4: 9.1 cm

Depth Model R-square: 0.9615

Summary

- Model is the product of interaction between two teams working with complex data sets
- Model has been validated and we have determined that it is highly accurate
- The science behind the spatial model has been peer reviewed

Questions?